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EMERGENCY AND PERMANENT CONTROL OF WIND EROSION IN THE GREAT PLAINS[1]

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I

SPECTACULAR dust storms of 1934 to 1937, which scattered rich soil from the Great Plains to places beyond the boundaries of continental United States, have brought into sharp relief the vital problems of agriculture in the vast semi-arid West. The storms came, generally, first from the southern sector of the Great Plains—the drought-ridden fields of the Texas-Oklahoma Panhandle, western Kansas, eastern Colorado and northeastern New Mexico—and then from the Plains States to the north. Drought and misuse of the land brought the scourge of wind erosion to an enormous total area. Water erosion has seriously affected an additional large area of rolling lands within the plains.

Human enterprise clashed with elemental forces of nature in the occupation of the Plains. That epic story of grass and cattle, of wheat and tractors, of drought and, finally, of dust can not be told adequately within the limits of this paper—but it can be summarized.

II

In the Great Plains, water is the beginning and end of agriculture. Without it there can be no crops, of course—and there also can be no vegetation to anchor the soil against the whirl of wind and the rush of water. Without water, cultivated soil, depleted of binding grass roots and accumulated spongy organic matter, is turned into a dry, powdery substance quite unlike the mellow, granular virgin soil. This powdery stuff starts to blow. Its fine, light particles are lifted into the high pathways of winds and are carried long distances unless rain or snow intercepts them. A residue of the virgin soil is left for the Plains farmer—the coarse material, as a rule, which is much looser, less stable and far less productive than that which is carried away. Drifting with the wind, usually in an easterly direction, this remaining material comes to rest in dunes. Each dune area represents the equivalent of an area of desert sand which will advance upon and at least temporarily cover good land to its lee. It is a constant menace to the land which lies beyond it, in the path of prevailing winds. Even when plants halt their movement, any disturbance of the cover by plowing or overgrazing will set these dunes in motion again.

An example of what happens to certain types of cultivated land under the impact of drought and wind illustrates the process of land decline in the Plains:

[1] Presented in a symposium on the Scientific Aspects of the Control of Drifting Soils. Denver meeting of the American Association for the Advancement of Science.

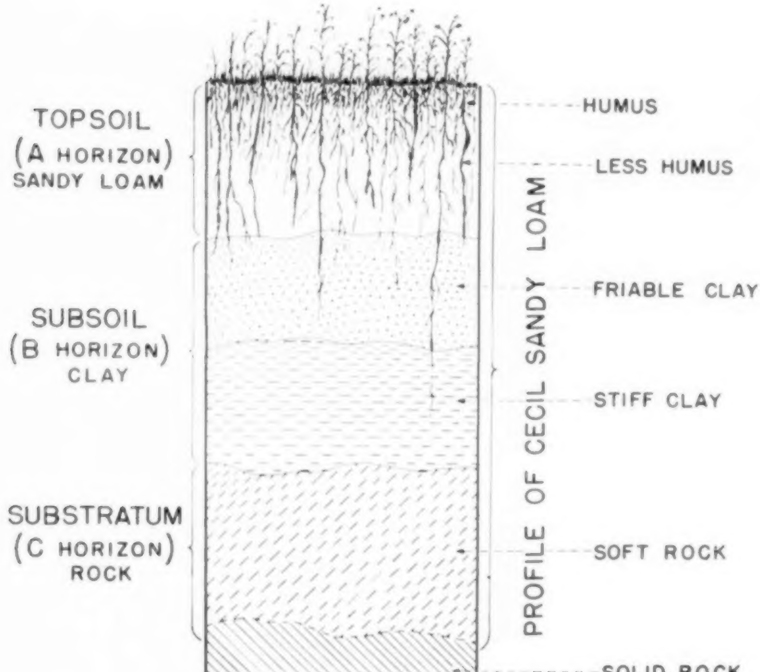

FIG. 1. A TYPICAL "SOIL PROFILE"
SHOWING GRADATION FROM FERTILE TOPSOIL AT THE SURFACE TO SOLID ROCK. SOIL-DRIFT REMOVES THE BEST PART OF THE TOPSOIL, LEAVING INFERIOR LAYERS BELOW IT.

During February, 1937, samples of dust were collected from snow and ice along the pathway of a dust storm that originated in the Texas-Oklahoma Panhandle and traveled across Kansas, Iowa, Minnesota and Michigan into Canada. A composite sample was taken from a small dune formed near Dalhart, Texas, by the storm that brewed this Canada-bound "duster," and another sample was secured from unplowed grassland in that vicinity. Dust collected 500 miles northeast of Dalhart, on grounds of the Soil Conservation Experiment Station near Clarinda, Iowa, contained ten times as much organic matter as the wind-assorted dune sand that was left behind. It also had 9.5 times as much nitrogen, 19 times as much phosphoric acid and 12 times as much fine material in the form of silt and clay. The dust contained 3 times as much organic matter as there was in the grassy soil near Dalhart, 3 times as much nitrogen, nearly 5 times as much phosphoric acid and about 5 times as much fine material. The sample of essentially virgin soil (unbroken grassland with virgin soil profile) contained 79.2 per cent. of sand, while the dune sample, representing what was left after blowing, contained 91.8 per cent. The dust deposited in Iowa contained no particles large enough to rank as even fine sand.

To an alarming extent, therefore, the fertile parts of the soil are blowing away; to an equally alarming extent, menacing, drifting sand is left behind. These evidences of increasing land decline emphasize two acute needs. We must find effective means to prevent, for all time, the breaking-up of any more loose, sandy land in the Plains, and we must turn back to stabilizing cover much farm land that already has been broken.

III

Soil-drift, typified in the results of this storm of 1937, presents three serious menaces. In the first place, it impoverishes fields by stripping the layer of rich topsoil down to depth of plowing or deeper. It also deposits wind-transported, sorted material in mounds of relatively unproductive, troublesome silt and sand. Finally, it threatens to develop great dune areas which may exceed all possibility of practical control. Since 1934, countless small and large dunes have formed on the Great Plains. Some are scattered and incidental; others exceed 1,000 acres in area and 10 feet in height, dominating the landscape of extensive regions. Their spread suggests conditions which prevail in parts of the Sahara border, as Ainslie[2] describes them:

ANALYSES SHOWING THE EFFECT OF A DUST STORM ON SOIL

	Virgin soil in grass near Dalhart, Texas	Sand dune, near Dalhart, Texas; formed during storm of February 6, 1937	Dust deposited by same storm on surface of snow near Clarinda, Iowa, February 8, 1937
	Per cent.	Per cent.	Per cent.
Organic matter	1.06	0.33	3.35
Nitrogen	.06	.02	.19
Phosphoric acid	.04	trace	.19
Potash	2.05	1.77	2.58
Sand	79.2	91.8	0.0
Silt and clay	19.5	7.5	97.0
Ultra-fine colloidal material	8.1	5.2	33.4

FIG. 3. WIND EROSION ON AN UNPROTECTED FIELD

IT WAS DISKED IN LATE FALL; ALL LOOSE SOIL WAS BLOWN AWAY THE FOLLOWING YEAR.

FIG. 2. SOIL STRIPPED TO PLOW DEPTH

BY A SINGLE DUST STORM. EAST-CENTRAL SOUTH DAKOTA.

A few months ago I had the opportunity of visiting the French Niger Colony lying to the North of the Nigerian boundary; that country is very largely desert and includes within its area probably the most dreaded desert region in the world; nevertheless, throughout the country there are many ruins of ancient towns and villages; it was evidently at one time heavily populated, and so must have been a well-watered region. There are both Arab and French records to show that up to the middle and towards

[2] J. R. Ainslie, "Forests in Relation to Climate, Water Conservation and Erosion." Bulletin 159, Department of Agriculture and Forestry, Union of South Africa.

FIG. 4. ABANDONED FARM
IN EAST-CENTRAL SOUTH DAKOTA, SHOWING DRIFTED AND DEPOSITED SOIL. 1935.

> the end of the 18th Century . . . these towns were inhabited by an active farming and trading people; the area, however, became deforested and it has only taken some 200 years to depopulate a country as large as the Union of South Africa. . . . First came the shifting cultivator with his axe and fire; secondly, the grazier with his camels, cattle, sheep and goats . . . and now comes the desert. . . .

If such changes take place on the Plains—if we fail to stabilize the dunes in time and permit them to coalesce and cover townships, counties or groups of counties—no exceptional vision is required to perceive the land anarchy which will follow the probable eastward march of sand across extensive areas of presently productive farms. No one can predict, of course, just how far the dunes may advance with prevailing winds before nature can check them with vegetation. We do know that in the geologic past sand dunes spread almost across Nebraska before bluestem and other plants finally anchored them. And in this connection, it is pertinent, I think, to notice that the Nebraska Sandhills furnish a splendid example of good land use. Most farmers of this region utilize these vegetatively stabilized dunes for moderate grazing, having learned from experience that cultivation or overgrazing immediately starts the sand to drifting.

I believe that Americans, duly aroused, have too much common sense to let soil-drift reach Nigerian proportions, especially since demonstrations have shown that blowing can be largely, if not entirely, controlled by practical farm and range methods and that young dunes can be halted by vegetation. It is true, however, that urgent requests for emergency control come from the Plains region year after year, indicating that temporary measures do not have effects which approximate permanent stability. Danger also lurks in the tendency of Americans to forget evils of the past when better times arrive—to forget during rainy periods the parched fields and grassless ranges, the dust and dust-induced diseases of severe drought years.

IV

When Denver was settled in 1858, a vast sea of grass extended eastward for hundreds of miles, short-grass predominating immediately to the east and beyond it the tall grass of the Plains border and prairies. Herds of buffalo migrated with the seasons from northern to southern pastures. With the coming of white man and the extension of railroads across the plains, these animals were slaughtered in countless numbers; except for local food supply, only their hides, horns, bones and tallow were used. Wanton destruction of the buffalo was a prelude to the land exploitation which followed.

First came the cattlemen. After the Civil War, the central and northern Great Plains were stocked with longhorn cattle from the ranges of Texas, and thousands of animals were driven over long trails to the markets or shipping points of the North and Northeast. Profits were good at first; speculation followed. By 1890, much of the Plains was stocked to capacity and during the five subsequent dry years the range was seriously depleted. Cattle died by the thousands, and investors both in the East and in Europe suffered tremendous losses.

Farmers gradually followed the cattlemen in a large and wide-spread area. As the humid lands farther east were settled, agriculture pushed westward, encroaching on the range despite protests from the ranchers, who temporarily convinced many persons that the Plains were not suited to agriculture. In some localities the land was divided into small farms to preclude speculation, but the 160 acres allotted under the Homestead Act generally were too small to support a family under sub-humid climatic conditions. During periods of heavier than average rainfall, however, farmers forgot past droughts and ignored the limitations imposed upon them by small farms. They often stated, and frequently believed, that "rainfall followed the plow" and that each new mile of railroad con-

FIG. 5. SOIL STABILIZATION BY PLANTING
ON THE SOUTH DAKOTA FARM OF FIG. 4. THIS SHOWS IT IN 1937.

FIG. 6. BURNING STUBBLE IN WESTERN KANSAS
THIS PRACTICE SIMPLIFIES PLOWING BUT DESTROYS NEEDED ORGANIC MATTER.

structed was an added guarantee of moisture. The Timber Culture Act of 1873 was passed in the hope that tree planting also would increase rainfall. Farming steadily moved westward, more and more sod was broken, and the organic content of the soil was dissipated by cultivation and oxidation.

When the sod was first broken, wind erosion was negligible and crops usually were good, but during the first drought thereafter, drifting and dust storms, "sand storms," frequently plagued the West. For more than 50 years individual Plains farmers have faced the menace of recurring drought and wind erosion. Recent dust storms are merely the accumulated result of long-continued exploitation, intensified by an unusually severe and protracted drought.

Most of the Plains was settled so slowly that soil blowing developed gradually, but Oklahoma presents a sharp contrast to this step-by-step progress. Its agricultural development waited until the various Indian reservations were opened to settlement. The land then was taken up rapidly, was cultivated and presented a serious problem of wind erosion within a period of less than 10 years. During this short time the farmers of the then Indian Territory developed through necessity a variety of means for checking soil-drift. Most of them served good purposes in some places and some proved helpful rather generally, yet the problem increased to proportions beyond control by individuals. This rapid development emphasized the relationship between land utilization and the erosion hazard with special clarity.

Soil drift was aggravated by economic necessity. Most of the original homesteaders lacked capital and had to grow cash crops, which usually were conducive to erosion. In periods of drought, crop failures were frequent. When the homesteaders failed, they were followed by short-period tenants to whom immediately profitable harvests also were neces-

sary. Neither owners nor tenants could survive without cheaply produced cash crops.

The hazard introduced by cultivation and destruction of the native sod was increased by climatic conditions. In Oklahoma, as in other sections of the Great Plains, droughts and periods of more than average rainfall recur at irregular intervals. One fourth of the year's precipitation frequently falls in a single month of spring or early summer, and as much as 15 or 16 per cent. of the year's total commonly descends in an hour. Within a single season farmers encounter problems of both water and wind erosion. In general, however, wind erosion is a major menace only in the western part of the state, while water erosion is statewide, though most destructive in eastern and central counties.

Wind erosion attracted attention first because dust clouds were conspicuous. In 1893, when the Cherokee Outlet was opened, incoming settlers were greeted by dust storms which began about September 10 and lasted two weeks. The dust evidently was blown from older cultivated areas beyond Oklahoma, but the storm itself should have served as a warning. Local drifting frequently began within two or three years after the land was plowed, especially where soils were sandy. From the first, warnings were sounded by a few experienced men, but they generally went unheeded. During the period from 1887 to 1901, the rainfall was heavier than average. Dust storms occurred, but they were less frequent, less severe and briefer than they had been. It was said, perhaps facetiously, that the south wind in Oklahoma had been discouraged by not finding dust to stir up and had quieted down. One observer remarked that "winds are becoming as much of a rarity as drought."

During the dry period, of 1901 to 1904, dust storms increased in numbers and

FIG. 7. THIS STUBBLE PREVENTS WIND EROSION
THE FIELD HAS BEEN DEEP-CHISELED, LEAVING PART OF THE STRAW ABOVE THE SURFACE, WHERE IT FORMS AN OBSTACLE TO WIND. BIG BEND SECTION OF WASHINGTON.

FIG. 8. STRIPS OF SUDAN GRASS AND CORN
THE STRIPS OF SUDAN GRASS PROTECT CORN LAND FROM WIND EROSION. TEXAS PLAINS, 1937.

extent, affecting much of the plowed land in western and central Oklahoma. Local soil movement increased to such an extent that the numerous swirls merged into dust storms of large proportions. Farmers who had never before experienced soil drifting began to complain. No longer could the problem be regarded as one to be solved by individuals.

From 1905 to 1908 the rainfall again was above normal and again the reports of drifting decreased, only to be revived once more during the dry period of 1909 to 1914. Drifting soil frequently covered entire fields of growing crops. In addition, the sand blew with such force that it often cut down young plants. A farmer in Major County reported that in three different years his alfalfa crop had been ruined in this manner.

V

Scientists did not wholly ignore the evils of wind erosion. As early as 1900 Professor Ten Eyck described the processes of deterioration which led to widespread soil-drift:

> When the wild prairie is first broken, the soil is mellow, moist and rich, producing abundant crops. After a few years of continuous cropping and cultivation, the physical condition of the soil changes; the soil grains become finer; the soil becomes more compact and heavier to handle; it dries out quicker than it used to; bakes worse. . . . After a soil has been cultivated and cropped a long time, it tends to run together and is very sticky when wet, but when dry the adhesive character disappears almost entirely. The grass roots which formerly held it together are decayed and gone, and now when loosened by the plow it is easily drifted and blown away.

In general, cover crops were regarded as the best means for controlling wind erosion. Various grasses, drought-resistant forage crops and dry-farming cultural practices, such as listing, were used. These did some good, at least locally. Bermuda grass (*Cynodon dactylon*), which was esteemed chiefly for its ability to hold the soil and prevent washing, was used to control both wind and water ero-

sion. Other grasses, such as Colorado grass (*Panicun texanum*) and crab grass (*Digitaria sanguinalis*), were tried. Alfalfa was regarded with special favor because it produced several crops of hay during a single year; but it was difficult to establish. Fall and winter winds often blew the seed from sandy fields; when good stands were obtained, the blowing sands of spring sometimes cut them to pieces. This was overcome, to some extent, by the use of a nurse crop. Many farmers sowed oats or sorghum in the spring and harvested the feed in August, leaving a stubble five or six inches high. Alfalfa was then sowed amid the stubble. The fall growth was usually killed by early frost, but was left standing for protective purposes. Some farmers combined oats with alfalfa in spring planting, but others preferred cowpeas because they both held the soil and improved it. Kafir, sweet clover and even wheat were tried, too. In some places, cropped fields were alternated with fields of native meadow or tame grass. In other regions, 10 rows of kafir were alternated with 10 rows of some contrasting crop.

Dead covers were used, as well as living ones. The farmers of some sections spread manure upon plowed or harvested fields. A smaller number of operators scattered straw and other trash, pressing them into the soil with disks. Stubble proved to be effective and cheap, yet neither it nor the other dead covers achieved general acceptance. The majority of farmers raked together all such litter and burned it, thus both destroying the protective cover and diminishing the humus supply of the soil.

Thousands of forest plantings were made in Oklahoma before 1907, originally in the hope that trees would bring rainfall. By the time that theory was ex-

FIG. 9. WATER AND RANGE-PLANT CONSERVATION
IT EMPLOYS A COMBINATION OF RESTRICTED GRAZING, PONDS AND CONTOUR FURROWING. TEXAS PLAINS, 1936.

FIG. 10. TERRACING ON ROLLING LANDS
CONSERVES WATER AND PREVENTS EROSION OF SOIL. OKLAHOMA, 1936.

ploded, the habit of planting trees was somewhat ingrained, and the use of trees as windbreaks was continued by a considerable number of farmers. Among the trees most used were Russian mulberry, black locust, osage orange and tamarisk. Much care was used in getting the trees started and, later, in cultivating them, but water was not artificially applied. A considerable number weathered the droughts, especially in situations most favorable to retention of rainfall and melting snow.

Cover crops generally were not cash crops, and the latter, as we have said, were necessary to the Oklahoma farmer. The dry farming boom greatly increased the acreage of cultivated plants. Dry farming, introduced at the end of a period whose rainfall was below average and coincident with a period of heavier rainfall, captured the imagination of the Oklahoma farmers and was hailed as the savior of agriculture on the Plains. The decrease in blowing during the second half of the nineties was, to a considerable extent, credited to dry farming, and it was said that Campbell, the method's chief advocate, had proved that drifting soils could be made practically stationary.

Campbell's methods of dry farming, whose principal element was soil mulching by cultivation, is familiar to those who have followed the agriculture of the Plains. In some places the system worked. Its big mistake was the assumption that a single method of cultivation was universally applicable, under all climatic conditions and on all types of soil. When dry periods recurred, blowing was increased, not only because the cultivated area was extended, but because the soil too often was left in a bare and finely pulverized condition favorable to wind movement. Campbell had recommended that the soil when plowed be left in a "small cloddy" condition, but that was impos-

sible on deep, sandy land. Although the system as a whole fell into disuse, certain elements of it continued in general practice and were modified to permit cultivation with a minimum amount of blowing. Deep fall and winter plowing thus persisted, though it was not recommended for loose sandy land. Even on other lands its effectiveness frequently was modified by climatic conditions during the winter. If the season turned out to be relatively wet, fall plowing proved satisfactory. If it did not, danger of blowing increased.

Gradually the lister replaced the turning plow, especially in spring planting. Crops were planted in the furrows which (where they followed the contours) served as reservoirs for rainfall. The intervening ridges made miniature windbreaks and were not entirely dragged down until growing crops protected the soil.

The disk harrow was almost as popular as the lister. Both were originally designed to conserve moisture and both emerged as tools for controlling soil-drift. The disk was used to roughen the soil, as a substitute for a packer, and to press stubble, trash or manure into the ground. In many places the use of the disk temporarily checked blowing, and it was considered the best tool available for that purpose.

During and immediately following the world war, mechanized agriculture developed, spreading rapidly across the Plains. Machines enabled the dry-country farmer to grow wheat at less than half the cost of production in the rougher but more humid lands to the east—at least, in years of favorable moisture. Low costs encouraged land speculation, and enormous new areas were planted to wheat. With the development of labor-saving machinery, farming often became a part-time job. A crop could be planted and harvested in six weeks, and farmers could spend the remainder of the year in other work. With two sources of income, they could

FIG. 11. BASIN-LISTING OF SUMMER FALLOW

ALTERNATED WITH STRIPS OF WHEAT. THE BASINS ARE VERY EFFECTIVE MEANS OF HOLDING RAINFALL. SOIL CONSERVATION PROJECT NEAR RAPID CITY, SOUTH DAKOTA, 1937.

FIG. 12. THESE DUNES ARE COMING UNDER CONTROL
FURROWING OF SPACES BETWEEN THEM PERMITS WEED GROWTH. THE CRESTS HAVE BEEN DRAGGED TO HELP WINDS REDISTRIBUTE THE SAND. DALLAM COUNTY, TEXAS, 1936.

afford to gamble on the weather in areas where full-time farming had not been economically possible.

Between 1920 and 1930, land values fell throughout the country; but in the High Plains of Kansas, Oklahoma and Texas, prices soared and population increased. From 1924 to 1929, crop land in the Great Plains increased by nearly 15,000,000 acres. This expansion was the immediate prelude to the major dust storms which accompanied drought in the '30's.

We have seen how some Oklahoma farmers curbed soil drift, but their example was not widely followed, even in their own state. There was virtually no attempt to develop a coordinated plan of erosion control, involving treatment of the various types of land, existing under different climatic conditions, according to their individual needs and adaptabilities. Some of the measures that were used extensively were improperly used. Listing, for example, was seldom on the contour, except by accident, so that one of its great values was missed, that of conserving rainfall.

In other parts of the Plains, such protective measures as strip-cropping were employed to some extent. On the whole, however, attempts to control erosion were pitifully meager. Countless farmers did nothing to hold the soil or conserve the rainfall. On the other hand, a great deal was done in the opposite direction, such as cultivating up and down the slope, burning or overgrazing crop stubbles, and plowing for seeding at times when the meager content of moisture in the soil indicated little opportunity to produce a reasonable yield.

VI

Emergency measures for controlling wind erosion usually are practiced *after* the soil begins to move. They take effect immediately and afford protection for

indefinite periods, which generally are brief. They consist principally of tillage operations which roughen the surface by listing, pocket fields with hole-digging or basin-listing machines, or which plow up resistant clods from the compact or fine-textured subsurface.

Other control measures include the application of foreign material, such as trash mulch, which is spread over or worked into the soil; off-season planting of cover crops; and removal of barriers likely to cause accumulation of drifts or hummocks. Mulching is rarely employed, because material is lacking. These practices are of emergency character if they are used after erosion actually gets under way, or when it threatens to start at any moment. They produce more lasting results, however, than does strictly emergency tillage.

It is very nearly true in the Plains that so long as the organic content of the soil remains low all agronomic measures for wind erosion control are emergency measures. It is also generally true that only a permanent cover of vegetation can afford more than temporary relief on deep, loose, sandy land and on shallow soil over dense caliche.

Permanent control involves a combination of precautions which will prevent the soil from getting into a condition which favors erosion. For the most part, such precautions are less immediate in their effect, but far more lasting, than those of emergency tillage. Unfortunately, permanent control measures may not take full effect within a year. Nor is every measure included in a permanent system for controlling erosion individually effective over the years. Some, such as contour listing and range contouring, may need to be repeated or re-installed; others, such as retirement of erosive land to permanent cover and the building of dams, are individually planned for permanency. Specifically, permanent control involves: (1) water conservation by detention, diversion and spreading struc-

FIG. 13. DRIFTING SAND AND DUNELETS
THE RESULT OF ONE-CROP FARMING, AFTER THE FARMER WAITED FIVE YEARS FOR A WHEAT CROP, FROM 1932 TO 1936. TEXAS PLAINS, 1936.

FIG. 14. RESTORATION OF A TEXAS FARM
THE CONDITIONS SHOWN IN FIG. 13 WERE QUICKLY IMPROVED BY TERRACING AND CONTOUR TILLAGE, WHICH CONSERVED WATER. SORGHUM THEN WAS PLANTED, IN A SYSTEM WHICH SELECTS THE BEST CROP FOR EACH SEASON. TEXAS PLAINS, 1937.

tures, and by contour-cultivation of fields and contour-furrowing of range land to promote continuity of vegetative cover; (2) the use of protective vegetated strips and borders of grass, crops, shrubs or trees; (3) the adaptation of crops and cultural practices to varying topographic, soil, moisture and seasonal conditions; (4) the conservative utilization of increased organic residues produced by these measures; (5) the retirement of critically erosive areas to permanent vegetative protection; and (6) the proper distribution and regulation of grazing on range lands.

The application of these principles involves the determination of the different needs of individual areas, the selection of a particular device or combination of devices to afford protection within the limitations of a particular tract of land, the selection of a combination of devices to meet jointly the needs of associated areas of land of different characteristics, and, finally, efficient application of the selected devices.

The most wide-spread opportunities for water conservation are to be found in runoff prevention on the heavier soils and diversion of runoff from waste land areas to sites of usefulness. Effective use of vegetation involves conservative regulation of grazing range land, crops and stubble, the prevention of burning of crop residues, the use of tillage methods which allow trash to remain on the ground, strip cropping and protective use of grass for the retirement of critically erosive areas. The greatest chance to use emergency cover crops probably occurs in early or mid-summer when rains are most likely to fall. The best opportunity to utilize border and strip designs is found in sites where waste water can be utilized in the support of windbreak tree plantings, and in fields

where the erosion-inducive or clean-tilled crops are grown or summer fallow is practiced. Emergency tillage operations are most likely to be needed in bare or thinly vegetated fields and in places where neighboring lands have been permitted to reach a condition which favors excessive blowing. In every case, when we apply these measures, we must determine what combination of methods is most economical and effective. Very rarely can we achieve adequate control by using a single method.

The ability of an economical combination of methods to effect reasonable control should determine changes in land use. For example, soils too sandy, too shallow or too infertile to permit economical maintenance of adequate vegetative cover from the residues of annual crops must be retired from cultivation and turned into grassland if adequate erosion control is to be achieved.

With proper land use and normal soil stability, emergency control measures should rarely, if ever, be needed. Farmers, facing the problem seriously for the first time, have found that they need emergency measures for temporary respite, or until opportunity permits something more lasting. In such circumstances, emergency methods are the first step toward permanent control.

Unfortunately, however, the magnitude of the immediate emergency problem in the most seriously affected areas has partly obscured the need for permanent control through a far-sighted precautionary program. Also, such repair work as the leveling of soil drifts and hummocks has been looked upon as final. These efforts are worse than useless, however, unless steps are taken to prevent recurrence of troublesome drifts. Indeed, this may be said of all emergency control.

It is hard to avoid the conclusion that unless vigorous steps are taken to effect permanent control, emergency efforts can not long be justified. The fallacy of reliance on temporary methods alone has

FIG. 15. CLODDY PLOWING IN A WIND-EROSION AREA
A MEANS OF HOLDING SOIL AND HALTING THE DEVELOPMENT OF SAND DUNES. DALLAM COUNTY, TEXAS, 1937.

FIG. 16. LISTING TRAPS WIND-DRIVEN SAND

FURROWS AND SPACES BETWEEN THE CLODS ARE FILLED WITH SAND, WHICH HAS SPREAD FROM THE DUNE THAT COVERED THE BARE MIDDLE GROUND. THIS AREA WILL BE DRILLED TO ROW CROPS DURING THE NEXT PLANTING SEASON. DALLAM COUNTY, TEXAS, 1937.

been amply demonstrated in many parts of the Plains during the recent long drought. The fact that farmers have been unable to control the situation with these temporary measures shows the need for a coordinated permanent program, which, properly directed and extended, will prevent recurrence of conditions now spreading in many localities.

VII

Recent studies by C. W. Thornthwaite,[3] of the Soil Conservation Service, indicate that the nature of the wind, as well as the physical characteristics of the soil, is important in the development of dust storms. Soil conditions favorable to blowing may exist for long periods, but unless atmospheric conditions produce wind velocities sufficient to transport the soil, no movement will take place.

The amount of soil transported and the distance to which it is carried depend on the detailed characteristics of atmospheric circulation. The wind is not a steady current of moving air. It comes in a succession of gusts and lulls which continually vary in direction, even though their average value may be maintained for hours at a time. This lack of uniformity comes from friction on the ground, which gives rise to eddies and whirls which resemble the eddies and whirlpools formed in rocky streams. Thus the great dust storms, such as the one of May 12, 1934, which darkened the sun over Washington, D. C., and extended beyond the Atlantic coast (the first event of that kind since white men came to America), grow from an enormously large number of little dust whirls blown up by gusts of wind passing over dry, loose soil.

When a current of air of one type replaces one of another type a considerable

[3] C. W. Thornthwaite, "Life History of Rainstorms." *Geog. Review*, 27: 92–111, 1937.

change in wind direction and velocity may take place within a very few minutes. On the other hand, large masses of air, many hundreds of miles in extent and frequently four or five miles deep, display great areal or horizontal uniformity in both temperature and humidity. Their principal characteristics are developed in regions over which they originate or remain for some time during their passage around the earth. Air-masses reaching the United States from northern Canada are cold and dry and are called Polar Continental; those arriving by way of the North Pacific Ocean are cold and comparatively moist, and are designated as Polar Pacific; those which come from the Gulf of Mexico and the tropical Atlantic Ocean are warm and very moist and are called Tropical Marine air masses. These are the three principal types of air which are involved in determining the daily weather and the climate of central United States.

Dust storms seem to be most frequently associated with Polar Pacific air masses. This type of air is characteristically turbulent; that is, there are many small vertical and horizontal currents within the large mass. These give the wind power to lift particles off the ground and to carry them along the surface or even into high air strata. In most of the dust storms that have been studied, the dust cloud developed with the arrival of the Polar Pacific air and lasted as long as this type of air remained. In many cases the storm ended as abruptly as it started, stopping when a Polar Continental air mass entered the dusty region. Polar Continental air lacks the turbulence of Polar Pacific air; it is cold and dry, and its ability to "clear the atmosphere" is due to its stability or lack of small vertical currents, even though its horizontal wind velocities often exceed those observed in the Polar Pacific air.

Wind velocities, especially in the upper air during dust storms, are often exceedingly high, as was shown by a storm in the latter part of February, 1936. This storm picked up soil from the northern Great Plains, carried it aloft, and in 25 or 30 hours transported it 1,500 to 2,000 miles to New England, where it returned to the earth with precipitation. During the dust storm of November 12 to 13, 1933, the wind at the surface reached velocities of 45 to 55 miles per hour at many places in North and South Dakota.

Dust storms, however, are only extreme manifestation of moving air's ability to lift and transport soil. Soil drifting may occur in any type of air whose surface layers have sufficient turbulence to pick up grains of silt or sand. Thus, Tropical Maritime air is usually quite unstable because of its high moisture content and temperature, or Polar Continental air, which has become warm and moist during its passage southward across the continent, may have enough lifting power to cause considerable soil-drift.

There is no other part of the interior United States in which average wind velocities are as high as they are on the Great Plains. Throughout most of the area, velocities average 10 to 12 miles per hour, but they reach 16 to 18 miles per hour in the Panhandles of Texas and Oklahoma and in the eastern Dakotas. Not only are averages high; throughout most of the Great Plains monthly variation is great. The highest velocities prevail in winter and spring, when the soil moisture is most frequently depleted and when the ground is bare and likely to be in the process of cultivation.

There is also a diurnal variation in wind velocity, which is pronounced except when it is obscured by the winds associated with the changes in type of air mass occupying given areas. Usually the wind velocity increases about two hours after sunrise and reaches a maximum about three o'clock in the afternoon. Some of the most severe wind erosion areas of the Dakotas and of the Texas-Oklahoma Panhandle are the very areas which have the

highest average wind velocities at three in the afternoon.[4]

I have mentioned these climatic relationships to indicate the complexity of the problems involved in control of wind-erosion and to emphasize the fact that we do not know all that we should about the numerous variables. We are studying them individually and collectively, with the hope that we may discover clews to new control devices and improve old ones.

VIII

In its demonstration projects and CCC camp work, the Soil Conservation Service is applying to the land in various parts of the Plains a coordinated program of soil and water conservation. It is using all known practical measures as rapidly as they can be fitted into the working plans to meet the diverse physical conditions of the land, the climatic environment and the economic situation. Such a program can not be carried out in all localities at a single stroke; but, as nearly as it can be done, this is the aim of the Service.

Several social and economic adjustments beyond the scope of the Soil Conservation Service program must be made in some localities. They include retirement of large blocks of unfavorable land from crop use, changes in the size of farms and ranches, improvement of the credit and tax situation, and the finding of more favorable lands for misplaced farmers.

The actual working procedure of the Service is based on detailed surveys indicating the kind of soil, the slope of the land, the degree of erosion, the vegetative cover and the present use of the various component parts of a farm or other operating unit. This means that for every area treated a blueprint and work plan are developed in advance. Then the Service applies a fully coordinated program of husbandry, involving the conservation of as much of the rainfall as possible.

The results obtained thus far have been decidedly encouraging. On some projects, virtually all the rain falling on fields and pastures has been directed into the reservoir of the soil by practical farm and ranch devices, while much or all of that which normally runs to waste down roadside ditches has been directed to useful purposes by diversion into fields or onto grass lands. This conservation of water has given great help to both established stands and new growths of protective vegetation, which are essential to effective control of blowing.

Conservation of water in small ponds for use of stock and man, as well as small-scale irrigation in favorable situations, also has been effectively fitted into the regional program. Surveys show that there are thousands of places where water now running to waste can be ponded or can be so diverted and spread as to perform good service.

A single erosion-control and water-conservation project illustrates the type of land treatment which the Soil Conservation Service carries on in various areas throughout the Plains. This is the Smoky Hill project, located in Cheyenne County, east-central Colorado. It comprises 160,000 acres of intermingled range and farm land, most of which has suffered in various degrees from wind erosion through the recent prolonged drought, many places having lost more than 6 inches of soil. Numerous bare areas have been cluttered with hummocks and dunes of accumulated wind-blown soil, necessitating extensive leveling operations before effective contouring and other necessary types of control work could be put into effect. Water erosion also has damaged much sloping land. The most severely affected land is that which at one time or another was cultivated. Over-

[4] C. Goodrich, *et al.*, "Migration and Economic Opportunity." Chapter 5 in "The Great Plains," by C. W. Thornthwaite. Philadelphia, University of Pennsylvania Press. 1936.

grazing has been a contributing factor, but it has not caused nearly so much damage as the plow.

The most important task was the conservation of enough moisture to supply a protective cover of vegetation. In the main, this has been accomplished by contour furrowing and terracing of grazing land by contour-listing and terracing of farm land. Thus far, these measures have held all the precipitation, and have distributed it so well that vegetation has begun to grow again over most of the 40,000 acres in which operations have been about completed. Most of the treated land has been fenced in order to control grazing. Much seeding has been done, many critical slopes have been subsoiled on the contour, dams to spread water or hold it for use by stock have been installed in favorable situations, and various other water-control measures and soil-holding farm practices have been installed or inaugurated. A highly important element of the program has been the retirement of critically erosive areas to the permanent protection of vegetation. As a result of these intensive methods, adjusted to diversified land conditions, comparatively little of the treated area is in a seriously blowing condition.

If farmers and ranchmen will carry on with these practical operations, and adjust themselves to a type of agriculture based largely on livestock, with a comparatively small area devoted to crops which are used chiefly for supplemental feed, accelerated erosion can be controlled in this part of the Plains. Moreover, a comfortable living can be earned from 3 or 4 sections or a little more, depending on the condition and quality of the land. On the other hand, there is every indication that any considerable departure from such a general plan of land utilization must lead to human poverty, as well as the eventual ruin of a large part of the Plains.

Success in the Smoky Hill Project and many others convinces me that we can protect the Great Plains and continue to use a large part of it for ranching and farming purposes, if we will. Many areas, to be sure, must be retired and turned into grazing reserves, protective grass areas and wild-life preserves, but this procedure also is needed in many other regions. The various grasses of the Plains must be brought into nurseries and cultivated to determine their practical possibilities as agents of conservation. Plant breeding must be carried on with the more promising native grasses, as well as with exotics.

By cooperating with nature, treating the land according to its needs and adaptability, conserving rainfall and making every possible use of vegetative measures of control, we can solve the Great Plains problem. This, of course, demands a permanent program, rather than dependence upon temporary measures which at best can only delay real achievement. The longer we delay permanent solution of the problem, the more difficult and costly it will be for either ourselves or our descendants to save and use the Great Plains.

ANIMAL PARASITES TRANSMISSIBLE TO MAN

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Introduction

Practically all vertebrate animals serve as hosts to parasites, and *Homo sapiens* is not an exception to this general rule. Actually man is an excellent host for various protozoan, helminth and arthropod parasites, the species adapted to live on or in human beings totaling several hundred. There is hardly an organ, tissue or cavity in the human body that is immune to the attacks of one kind of parasite or another. Such vital organs as the liver, spleen, lungs, heart, brain, eyes, and others too numerous to mention are susceptible to invasion by parasites that are capable of inflicting serious damage to the parts of the body that are invaded.

Human beings acquire parasites through some form of contamination, usually traceable to soil pollution, through the consumption of raw food of animal origin, and in other ways. In parts of the world where sanitation and hygienic standards are far below the levels that are accepted in most civilized countries, parasites that are acquired through contaminated food and water constitute an important health factor; in tropical countries they are usually one of the most important health factors. In countries where the level of sanitation is high and where the standards of hygiene are exacting, parasitism that spreads ordinarily through soil pollution tends to disappear, more particularly in urban communities. In rural sections, however, including those of this country, there is always a greater or lesser residuum of parasitic infection of one kind or another, and urbanites who visit the country for rest and recreation may acquire a few unwelcome guests, such as hookworms, ascarids, whipworms, dysentery-producing amoebae and other parasites, which occur as infective eggs, cysts or larvae in contaminated soil.

By and large, however, human beings living in cities and towns are in most cases adequately protected from acquiring parasitic infestations to which rural inhabitants may be exposed as a result of contact with the soil. The nation-wide campaign against soil pollution, undertaken in this country on a large scale in the beginning of the twentieth century, has done much to reduce the danger of acquiring parasitic infestations, even in rural areas. Several years ago the annual report of the Rockefeller Foundation contained the statement that hookworm disease, for years an important factor in the physical and mental retardation of the population of rural areas in certain parts of the South, had been practically eradicated. While this statement was open to challenge at the time that it was published and was challenged vigorously, the fact remains that the hookworm incidence and intensity in the United States have been greatly reduced, thanks to the activities of such agencies as the U. S. Public Health Service, the Rockefeller Foundation, the state boards of health and local health units in the South.

While progress in the control of human parasitic infestations traceable to soil pollution has been steady and on the whole satisfactory, that relating to the control of parasites of man that are acquired from consuming animal food still leaves much to be desired. Actually, the available evidence shows that one human tapeworm infestation acquired from certain species of fresh-water fish is spread-

ing in the United States, although its distribution is still rather limited. Trichinosis, a serious, painful and sometimes a fatal disease of man, is apparently gaining headway. Whether the increase in the number of cases of human trichinosis is only apparent because of the greater vigilance on the part of physicians in making a correct diagnosis, or whether the increase in the number of such cases is real, is difficult to determine on the basis of available evidence. The extent of beef tapeworm infestation, in so far as this can be determined from the data on the prevalence of the larval stages of these parasites in cattle slaughtered under federal inspection, shows that during the past ten years or so this parasite has been holding its ground, although the data of previous years showed a downward trend.

The parasites mentioned, namely, the fish tapeworm, the beef tapeworm and trichina, are the most important parasites of man in the United States that are transmitted through the consumption of animal food. The pork tapeworm, though only of slight importance in this country, must be added to the list. We shall briefly consider each of these parasites and its bearing on human health.

The Fish Tapeworm

The so-called fish tapeworm, *Diphyllobothrium latum*, is really a human tapeworm that spends part of its early life (plerocercoid stage) in certain species of fresh-water fish. According to Wardle the following species of fish in North America are known to be intermediate hosts of the tapeworm under discussion: Pike, *Esox estor;* pickerel, *Stizostedion vitreum*; sauger or sand pike, *Cynoperca canadense*; and perch, *Perca flavescens.* Prior to getting into fishes this parasite occurs as a larva in fresh-water copepods or so-called water fleas, that constitute a part of the microscopic and near-microscopic aquatic life—plankton—which is an important item in the food of fishes. The life cycle of the tapeworm is rather complicated and is briefly as follows:

The tapeworm, which may attain a length of about twenty-five feet and, in exceptional cases, a length of sixty feet, in the human intestine, produces eggs which are microscopic in size and which are eliminated from the ripe or gravid tapeworm segments into the lumen of the host's intestine. Occasionally long chains containing as many as one hundred or more segments may be passed with the excreta of infested animals, including dogs, cats and wild carnivores, such as bears and foxes, that also serve as hosts of this tapeworm. The tapeworm eggs passed with excreta and those which become liberated from the passed segments, as a result of the disintegration of the latter, hatch in water following their normal development. The newly hatched larvae, provided with cilia, may be swallowed by copepods which are usually found teeming in fresh-water lakes. When swallowed by suitable intermediate hosts the larvae undergo further development but do not become infective to man and other definitive hosts unless they reach the body of a second intermediate host, namely, a suitable species of fish, as already noted, and develop there to the plerocercoid stage that is infective to mammals. Fishes become infested by swallowing the infested copepods, and human beings acquire the fish tapeworm as a result of eating raw, or nearly raw, or cold-smoked or salted fish that harbors the stages of the parasites infective to man.

According to Magath the Finlanders, as well as other northern Europeans in Minnesota, have retained their native fondness for raw fish, and the more nearly raw the fish is the better the Finlanders like it. Magath makes the following statements: "One Finlander

remarked that he was in the habit of not carrying a luncheon on a fishing trip, being satisfied with the raw fish he caught. A common dish is fish which has been salted in brine for twenty-four hours and cut up with green peppers, cabbage and cucumbers, while some bury the raw fish for a few days to ripen it, then eat it with salt."

At one time there was considerable discussion among parasitologists as to whether the fish tapeworm could complete its life cycle in North America, some investigators taking the position that infested persons in this country must have acquired this parasite abroad. It has been definitely established, however, that the fish tapeworm has become endemic in North America and many cases of infestation of native origin have been traced. Fishes from the Great Lakes region of the United States have been found to be naturally infested, and species of copepods that are capable of serving as the first intermediate host have been shown to be susceptible to experimental infection. Thus, the entire life cycle of this tapeworm can take place in North America, and this parasite, originally introduced into this country by immigrants from northern Europe, is now definitely established in the United States. According to Ward the belt of infection stretches across the Great Lakes, includes the upper Mississippi basin, even reaching out into Iowa, crosses the height of land into Manitoba and embraces lakes almost to the Rockies.

Once having gained a foothold, it is easy to see how this parasite established itself solidly, since untreated sewage from cities and towns is commonly emptied into lakes. Infested immigrants coming to North America from countries along the shores of the Baltic and from other areas where this infestation is common, polluted the lakes in some of our North Central States and other regions.

In parts of Scandinavia, Finland, Russia and Germany, bordering on the Baltic and connecting waters, the local population shows an incidence of infestation up to 50 per cent. or more. Even a few infested immigrants could have greatly polluted our fresh-water lakes, since it has been estimated that an infested person may discharge at least one million tapeworm eggs a day. The fondness of certain people of European origin for raw fish, or portions thereof raw, or lightly salted or pickled, has served to propagate this infestation in this country. The susceptibility of the dogs, cats and various wild carnivores to this parasite has added a further complication tending to increase the spread of this tapeworm.

Persons infested with the fish tapeworm may exhibit nervousness, loss of sleep, experience creeping feelings and occasionally show a voracious appetite. The symptoms manifest themselves particularly after a person discovers that he or she is infested, this indicating that the symptoms, at least in part, are probably mental rather than physical. Of special interest in connection with this parasite is the occurrence in a very small percentage of infested persons of an anemia that is indistinguishable from pernicious anemia. However, precise information is still lacking with regard to the causal relation of the parasite to the cases of pernicious anemia observed in infested subjects.

The prevention of infestation with the fish tapeworm is simple and absolutely effective. Fresh-water fishes should not be eaten raw, semi-raw, cold-smoked or lightly cured in salt. Thorough cooking of fish is an absolute prevention and can be relied upon as being a one-hundred per cent. prophylactic measure.

The Beef Tapeworm

The beef tapeworm, *Taenia saginata,*

occurs in its adult stage solely in the human intestine where it may attain a length of about thirteen to forty feet. Usually an infested person harbors but a single tapeworm, the occurrence of one worm in the intestine apparently excluding others from developing.

The life cycle of the beef tapeworm is similar to that of the fish tapeworm, except that but one intermediate host, namely, a bovine, is required. Human beings become infested solely as a result of eating raw or rare beef containing the larval stage of the tapeworm infective to man, and cattle become infested with the larval or cystic stage as a result of swallowing the tapeworm eggs with feed or water that has become contaminated in one way or another with the excreta of a tapeworm carrier. The life history of the beef tapeworm involves, therefore, an alternation between two hosts, man and the ox.

Ransom pointed out years ago that a single individual with a tapeworm is a peripatetic center of infection. Each gravid segment of a tapeworm contains several thousand eggs, and several segments may become gravid and expelled every day during a period that may extend over several years. Thus hundreds of cattle might become infested from a single tapeworm carrier, if this person happens to live in a rural district where cattle are raised.

The control of infestation of cattle with the larval stages of this tapeworm will inevitably result in the control of the beef tapeworm infestation in man, and *vice versa*. Reduced to simple terms, improvement in conditions as regards the disposal of human excreta in rural sections will prevent cattle from becoming infested, and this in turn will tend to reduce and ultimately eliminate the infestation in man.

As an example of the unsanitary conditions that prevail in some rural sections of the United States, particularly as regards the disposal of human excreta, an outbreak of larval tapeworm infestation in cattle, technically known as cysticercosis, was investigated by the Bureau of Animal Industry a number of years ago with the following results:

Following the detection under federal meat inspection procedure of a heavy infestation of cysticercosis in 3 lots of cattle which came from the same locality, 105 out of 523 cattle, or 20 per cent., being infested, it was determined that about 1,500 cattle, of which the 523 were a part, had been fed during the winter and spring in the yards of a cottonseed oil mill. These animals were later marketed at various live-stock centers and data were obtained on the 523 animals already referred to. The remaining animals were not traced to the point of slaughter.

The investigation made at the yards of the mill disclosed that the regular water supply for the cattle was taken from a river 75 yards below a sewer outlet. The river was wide and shallow, had a sluggish current, and the banks, which formed a portion of tract of land designed for a public park, were strewn with human feces. The investigation disclosed further that the cottonseed hulls used for feeding the cattle were stored in a building where tramps commonly slept during the feeding season. Evidence was obtained which indicated that the cottonseed hulls had become more or less contaminated with human excreta, the hull house being used evidently by the tramps and mill employees as a place for defecation, especially during very cold weather. An inspection of the 3 outhouse toilets intended for the use of the mill employees showed that the structures were of poor design, the excreta falling directly on the ground or in boxes set on the ground level. As many of the mill employees using these outhouses were transients, it was estimated that about 200 persons used the three poorly constructed and unsanitary outhouses dur-

ing the cattle feeding season. At the lower end of the feed yards there was a stagnant pool which drained a watershed that included a portion of the town and cottonseed oil mill with its three primitive outhouses. The cattle were occasionally forced to drink from this stagnant pool as a result of frozen pipes which shut off the regular water supply. The 1,500 cattle fed at the yards were therefore exposed to the following sources of infection with tapeworm: (1) The outhouses which drained into the stagnant pool; (2) the regular water supply from the sewage-laden river; (3) the cottonseed hulls, which were more or less subject to contamination, and (4) a portion of the town's waste which drained into the stagnant pool. That fully 20 per cent. of the cattle that were fed under these unsanitary conditions became infected, as shown by the data obtained, is not surprising considering the four possible sources of infection.

Two recent outbreaks of cysticercosis in cattle, investigated by the Bureau of Animal Industry, showed conclusively the important role of a single human tapeworm carrier as a spreader of this parasitic infestation to bovines. The facts in these cases are as follows:

Following the receipt of information that 166 out of 252 cattle carcasses were retained in an officially inspected establishment at Fort Worth, Texas, because of infestation with tapeworm cysts, an investigation was made of the premises where these cattle had been fattened for market. It was determined that the bovines in question were kept in a feed lot to which feed was hauled by an individual who later was found to be responsible for the outbreak of cysticercosis. When the owner of the cattle was informed of the retention of a number of beef carcasses, as already noted, from the particular lot of cattle in question, all men on the ranch that were connected in one way or another with the feeding of these animals were examined by a physician, and the individual referred to was found to be infested with a tapeworm. According to the information furnished "about 20 feet of tapeworm" were removed from the person following the administration of a taeniacide. Upon being questioned, the tapeworm carrier admitted that he did not like cooked meat and, therefore, "ate all his meat raw."

The premises to which this and other persons connected with the feeding of the cattle had access had no toilet facilities, and the infested person was seen, on numerous occasions, to defecate in the feed troughs.

In an officially inspected establishment in Oklahoma City, Oklahoma, twelve out of thirty-seven cattle carcasses were retained recently because of infestations with cysticerci. In tracing the origin of these cattle, it was determined that they came from a farm that had no toilet facilities, the barn and chicken house being used as places for defecation by a man and his wife who had charge of the cattle-feeding operations. The only source of water supply for the cattle was a small pond located about a hundred yards from the farm house; all the drainage from the dwelling, barn and chicken house ran directly into this pond. Through the assistance of the State Board of Health, it was determined that the wife of the cattle feeder, who complained of being sick, was infested with *Taenia saginata*. Considering the primitive conditions under which this couple lived, it is not surprising that one third of the cattle that were fed on this farm became infested with tapeworm cysts.

While the consumption of raw or slightly cured fish will probably strike the readers of this article as a freak habit of certain northern European immigrants, the consumption of raw and rare beef is certainly a well-established American custom. Steaks cooked rare

are frequently raw in the middle, and rare roast beef is certainly a common American dish. It is not surprising, therefore, that infestation with the beef tapeworm is quite common in the United States. No adequate statistical information is available on this point, since there is no agency in the United States for collecting this sort of information. Several physicians with whom the writer of this paper has discussed this point stated that cases of human tapeworm infestation are encountered by them, sometimes several times a year in routine practice. That tapeworm infestation in man is not more common in this country is due entirely to the protection that is afforded to the consumer by the vigilant federal meat inspection service and competent state and local meat inspection units.

Beef tapeworm infestation in man occurs in all parts of the world where beef is used for food. In Abyssinia, where beef is regularly eaten raw, practically the entire population is infested; in certain parts of Syria, one third of the population is infested. In countries where beef is commonly cooked the extent of the infestation is more limited.

Under federal meat inspection beef carcasses showing an excessive infestation with tapeworm cysts are not passed for human food, thus cutting off the most fertile source of infection. During the past five years, the total number of beef carcasses condemned on account of tapeworm infestation was somewhat under 1,000 out of a total of over 50 million cattle slaughtered under federal inspection. During the same period, however, over 135,000 beef carcasses were retained on account of infestation with tapeworm cysts. Under federal meat inspection the retained carcasses which contain only one dead and degenerated cyst are passed for food following the removal of the cyst and adjacent parts, and a careful inspection to make sure that no other cysts are present; carcasses showing a moderate infestation are not passed until after the removal of all visible cysts and subsequent refrigeration of the carcasses for a period of not less than six days and at a temperature definitely known to be fatal to the vitality of these parasites, or such carcasses are cooked at a temperature that is known to be destructive to the vitality of these tapeworm larvae. Carcasses showing a heavy infestation, or a pathological condition of the muscles indicative of such infestation, are condemned.

It should be borne in mind, however, that only about two thirds of the food animals slaughtered in the United States are subject to federal inspection, the remaining third being slaughtered in many cases under no inspection or under imperfect inspection. Slaughtering done on the farm for home consumption is not, of course, subject to any official inspection. Actually, however, even the best kind of inspection can not guarantee perfect results so far as the detection of tapeworm cysts in beef is concerned, because in most cases the degree of infestation is slight and a large proportion of slightly infested carcasses necessarily escape even the most careful inspection. The actual number of cases of infestation in cattle with larval tapeworms is probably much greater than that shown by the figures cited. From a practical viewpoint, however, it seems scarcely possible to effect a more thorough inspection for tapeworm cysts than is done under existing requirements. The inspection that is made eliminates most of the carcasses that are likely to transmit tapeworm infestation to human beings; the carcasses that are passed without detecting these parasites probably have only slight or almost negligible infestations.

As in the case of the fish tapeworm, the beef tapeworm in many cases may produce no noticeable symptoms. This

is particularly true of cases involving robust individuals. Delicate and nervous persons and children may show, at times, rather alarming symptoms, including severe gastro-intestinal disturbances, nausea and vomiting. Nervous persons may show convulsions and even some severe reactions that are suggestive of epilepsy. Sometimes tapeworm infestation gives rise to emaciation and anemia. On the whole, tapeworm infestation does not produce serious illness, the severe symptoms mentioned being the exception rather than the rule. Effective treatments for the removal of tapeworms from man have been established, and persons affected should seek the advice of a physician.

Prevention is simple and effective. To avoid tapeworm infestation cook beef until it is well done.

The Pork Tapeworm

Aside from being somewhat shorter, as a rule, the pork tapeworm, *Taenia solium*, bears a very close resemblance to beef tapeworm. Like the beef tapeworm, the pork tapeworm lodges in the small intestine of human beings, its head being provided with hooks that afford the possibility of a firmer anchorage to the intestinal wall than in the case of the beef tapeworm, which lacks this armature. Ordinarily the pork tapeworm is from about two and one half to five feet long, but it may attain, at times, a length of about twenty-five feet. Its life cycle is essentially similar to that of the beef tapeworm, except, of course, that the hog serves as the intermediate host. Human beings become infested with the pork tapeworm by swallowing infested raw or insufficiently cooked pork, and hogs in turn become infested with the cystic stage by swallowing feed or water that has become contaminated with human excreta passed by infested persons. The life history of the pork tapeworm thus consists in an alternation between two hosts, man and swine. The reduction in the incidence of infestation in swine necessarily leads to a reduction in the incidence of infestation in man, and *vice versa*.

Actually the pork tapeworm is very rare in man in this country; the rarity of this parasite in human beings is directly correlated with the rarity of the cystic stage in swine. This is a very fortunate situation, because from the view-point of its bearing on human health, the pork tapeworm is far more dangerous than the beef tapeworm. So far as the production of intestinal disturbances and nervous symptoms in infested individuals is concerned, the two species under consideration are on a par. Unfortunately, however, man is also capable of serving as an intermediate host of the pork tapeworm and thus becoming infested with the cystic or bladderworm stage. Since the cysts may lodge in such organs as the heart, the brain and the eye, an infestation in man with the cystic stage of pork tapeworm may lead to serious consequences and often does. Persons harboring the pork tapeworm in the intestine might accidentally contaminate their hands with the tapeworm eggs. It requires but little imagination to see how the hands thus contaminated might transfer the eggs to mouth and thus pave the way for an infection of the muscles and of such vital organs as the heart, brain and eyes. Several years ago a medical officer of the British Army reported the pork tapeworm as a rather common cause of epilepsy in British troops returning from abroad, presumably from places where the cystic stage of the pork tapeworm was of rather common occurrence in swine, the epileptiform symptoms being due, of course, to the lodgment of the cysts in the brain and other parts of the central nervous system.

Under federal meat inspection swine carcasses showing a light infestation with tapeworm cysts are passed for sterilization, which means thorough cooking at a temperature more than adequate to destroy life in these parasites; if the infestation is moderate or excessive the carcass is condemned.

For many years it was assumed that the rarity of the pork tapeworm in man and swine in this country was due to the fact that the American people were not in the habit of eating rare or raw pork, a habit which is well established among the people of certain countries of Europe. Unfortunately, in the light of the evidence to be presented in connection with the next and final topic, trichinosis, this assumption does not appear to afford the entire explanation. Federal and other competent meat inspection offer the public the greatest measure of protection against the pork tapeworm. The importance of cooking pork thoroughly will be discussed in connection with trichinosis. Thorough cooking of pork will absolutely preclude the possibility of infestation with a tapeworm that is very dangerous to human health.

Trichinosis

Trichinosis is a disease of human beings, swine and other animals. The parasites which produce this disease are small cylindrical worms, known to zoologists as *Trichinella spiralis* and commonly known as trichinae; these parasites occur in a great variety of carnivorous and omnivorous mammals. So far as human trichinosis in this country is concerned, only swine need be taken into consideration, since practically all the known cases of human trichinosis in the United States that have been definitely traced to their source were shown to have resulted from the consumption of raw or undercooked infested pork or to the consumption of inadequately cooked or cured meat food products containing infested pork muscle tissue. A few cases of trichinosis have been traced in this country to the consumption of jerked bear meat, and in Germany this food was responsible for a serious outbreak of trichinosis several years ago.

Unfortunately, pork that is infested with trichinae does not differ in appearance or in taste from uninfested pork. The trichinae that occur in the flesh of hogs are very small, measuring only about one twenty-fifth of an inch in length and about one eight-hundredth of an inch in width. The individual worms are spirally rolled and enclosed in capsules which are somewhat less than one fiftieth of an inch in diameter and hence, microscopic in size. The capsules do not stand out in contrast to the meat, except in infestations of long standing. Considering the minute size of encapsuled trichinae, it is impossible, of course, under meat inspection procedure, to detect their presence in pork with the naked eye. Microscopic inspection of pork for trichinae is practiced in some European countries. Such inspection, however, is inherently imperfect, many infected carcasses, especially those moderately or lightly infected, being overlooked. Knowledge of the existence of a microscopic inspection of pork would tend to create a false sense of security in the minds of persons who are fond of raw pork, and this would tend to promote rather than discourage the unhygienic custom of eating pork in a raw or semicooked state. In the United States, microscopic inspection for trichinae of pork intended for home consumption has never been undertaken. Consequently, pork that is passed under federal and other meat inspection as being fit for human food may be infested with trichinae, and for this reason pork should always be cooked. If infested pork is eaten raw or insufficiently cooked, seri-

ous consequences are apt to follow and sometimes do.

During the year 1937 three serious outbreaks of trichinosis were reported in the press. Through official correspondence, the Bureau of Animal Industry ascertained the facts in each outbreak from the health officer of the community concerned or from the physician who treated the patients. These three outbreaks illustrate how trichinosis may be contracted and afford information on the seriousness of this disease.

Early in December of last year, a farmer, Mr. X, living in Flathead County, Montana, a Russian by birth, and the father of eighteen children, prepared a lot of smoked sausage which contained venison mixed with pork obtained from hogs slaughtered on his own premises.[1] These sausages were eaten by X and his immediate family. Some of these home-made sausages were distributed by the kindly father to his married sons and daughters, and they in turn, partook of these home-made products and, with characteristic western hospitality, distributed the surplus products to their friends and neighbors. The available evidence indicates that the immediate family of X, and some members of the families of his sons and daughters and those of some of their friends ate these products without cooking or only after slight cooking or warming. As a consequence thirty-eight persons became ill, Mr. X and members of his immediate family being the first ones to show symptoms of illness.

The first symptoms shown by the members of the stricken family were a general tired feeling and headache, these being followed by nausea, vomiting and sharp gastro-intestinal pains. These early symptoms were followed later by pains in the eyes and a marked swelling of the lower eyelids; at the same time marked swellings were noted in the muscles of the lower portion of the abdomen and in the flexor muscles of the limbs. The symptoms mentioned, especially the early symptoms, were, in the opinion of the attending physician, suggestive of food poisoning, and it was suspected that the venison which was one of the constituents of the sausage might have been tainted. As the patients failed to improve, but grew instead increasingly worse and developed fever, the state epidemiologist, who was notified of this outbreak, visited the premises, and obtained samples of water and samples of blood and stools from the infected persons. The samples were submitted to the state health laboratory for bacteriological examination; the results were negative. The youngest member of the family in the meanwhile became severely ill and was placed in a hospital, where the usual laboratory examinations were made, including a microscopic examination of the spinal fluid, a spinal puncture having been resorted to because meningitis was suspected. One microscopic field showed a single trichina larva, and this at once led to a suspicion that the patient, as well as the other members of the family, was suffering from trichinosis. Samples of the pork sausage still available on the farm were sent immediately to the laboratory of the Montana Livestock Sanitary Board, and a telegraphic report from that laboratory to the hospital contained the information that the sausage was heavily infested with trichinae. The hospitalized patient succumbed to the infection about three weeks after eating the infested sausage. In the meanwhile other persons outside of X's immediate family became ill and on the date of the last report 38 persons, as already noted, were ill and suffering from trichinosis.

The symptoms shown by the affected persons were due to the progress in the growth, development and migration of

[1] The account of this outbreak is based on information supplied by the attending physician.

the trichinae in the bodies of their victims. The early gastro-intestinal irritation and pain were the result of the growth and development of the worms in the intestine, and the swellings and pain in the muscles were caused by the penetration into this tissue of the newborn trichinae, which wandered from the intestine in the lymph and blood stream until they reached the muscles. The symptoms which were suggestive of meningitis were due, at least in part, to the penetration of the wandering worms into the central nervous system.

One of X's daughters ate some of the sausage well cooked and escaped infection, while several members of her family who ate the sausage only half-cooked became ill. A neighbor of one of the beneficiaries of X's generosity is said to have stolen a number of sausages and his family of five, including himself, became stricken with trichinosis.

A sample of the sausage that brought about this epidemic was forwarded to the Bureau of Animal Industry and was found in our laboratory to contain approximately 2,800 trichina larvae per ounce. A piece of muscle from one of eleven hogs purchased from X by the Montana Livestock Sanitary Board and later slaughtered was examined in our laboratory and found to contain an average of about 168,000 trichinae per ounce.

This outbreak has been described in detail because it illustrates the point that human beings acquire trichinosis from eating raw or slightly cooked pork, shows the principal symptoms of trichinosis, and that this disease may terminate in death. The data given afford conclusive proof that the suffering of those stricken as well as the untimely death of the youngest member of the family could have been avoided, if the sausage in question had been cooked, as shown by the experience of one of X's daughters, who apparently did not share her family's fondness for semi-raw pork. The case history of the boy who succumbed to trichinosis illustrates that this disease may be confused with other febrile diseases, such as food poisoning and meningitis. Trichinosis is commonly confused with typhoid fever and occasionally with undulant fever.

Another outbreak which occurred late in October of last year involved forty-four persons in one of the New England states. Fortunately all these cases were moderate or mild. The infection was traced to a meal of undercooked pork loin of which all the persons who later became ill partook. The diagnosis in these cases was established on the basis of clinical symptoms.

Still another outbreak occurred late in the summer in Rochester, New York, and came about as follows: A social organization of that city held a picnic, which was attended by about 200 members. The food served was of the customary picnic variety, including pork sausage, which was cooked hurriedly and avidly consumed by the picnickers, following several hours of exercise in the open. The resultant casualties were as follows: Stricken with trichinosis, 85; succumbed to the disease, 1. Aside from the fatal case, only a few individuals developed sufficiently severe symptoms to warrant hospitalization; most of those stricken escaped with rather mild symptoms and were treated in their homes. An article regarding this outbreak, published in the bulletin of the Health Bureau of Rochester, New York, contains the following significant statement: "All this suffering could have been so easily prevented, if only the pork had been thoroughly cooked."

The total number of cases involved in the three outbreaks is 167, with two deaths. In addition to these cases, there occurred during the year a number of more or less isolated cases in various

parts of the country which probably will bring the total number of reported cases of the year up to about 250.

In the absence of an economically practical method of inspection of pork to detect infected carcasses and in the absence of a practical system of rendering fresh pork and ordinary varieties of cured pork safe for consumption before the meat is released for sale, the consumer should protect himself by cooking all pork thoroughly, unless he has definite assurance that a particular processed pork product intended to be eaten without cooking was prepared with this in mind in a meat-packing establishment operating under federal inspection or competent state or local inspection. Whenever any doubt exists as to whether a particular product may be eaten without cooking, it should be cooked thoroughly.

Under federal meat inspection, all products containing pork muscle tissue that are to be sold as cooked products are heated or cooked under the scrutiny of inspectors, according to methods which are known to insure a sufficiently high temperature to destroy in all parts of the meat the vitality of any trichinae that may be present. For all products which are not cooked or heated to a sufficiently high temperature, but which are nevertheless intended to be eaten by the consumer without cooking, various alternative methods of preparation are prescribed, such as prolonged freezing at low temperatures, or curing, smoking and drying in accordance with methods that are known to insure the destruction of life in all trichinae present. As already stated, for fresh pork and ordinary varieties of cured pork, there is no inspection or required treatment for reasons already given.

Some persons, upon discovering that between 1 and 2 per cent. of hogs in this country contain trichinae, and that these parasites are dangerous to human health, conclude that all pork, no matter how prepared, is dangerous. Such a conclusion is unsound and unwarranted. There is no danger whatsoever of acquiring trichinosis or any other parasitic disease from thoroughly cooked pork. Cooking of pork is a health safeguard and is comparable to the pasteurization of milk, the chlorination of drinking water and similar hygienic measures that have been adopted the world over to protect human health. If one concludes that there is something wrong with pork because it must be cooked to make it safe, to be consistent such a person would also have to conclude that there must be something wrong with milk because it is commonly pasteurized. As is well known to hygienists, cooking is the greatest health safeguard; the facts presented in this paper confirm this generalization.

THE SURFACE OF THE NEAREST STAR

By Dr. ROBERT R. McMATH
THE MCMATH-HULBERT OBSERVATORY, UNIVERSITY OF MICHIGAN

The atoms in the surfaces of all the billions of stars accessible with our telescopes may fittingly be compared to minute sending stations, broadcasting each on its appointed multitude of narrow wave-length bands, preserving their allotted "channels" with almost infinite exactitude and endeavoring thus to send us certain important messages relating to the temperature and the constitution of the stars in which they are located. With our telescopes, and to a far greater extent with those optical receiving stations we call spectrographs, we are today reading a few of the messages these distant stars are endeavoring to broadcast to us.

Certain equally important messages relating to the actual spatial behavior and physical movements in stellar surfaces seem, however, permanently beyond our reach. For no telescope, existing, projected or imaginable, can show a star to us as anything but a diskless point of light; an actual stellar diameter of a million miles or more will vanish almost into a mathematical point at stellar distances of trillions or quadrillions of miles.

Thus it becomes very fortunate for our knowledge of the distant stars that we have a star so close at hand that we can see its disk and study the actual motions on its surface. The star referred to is, of course, our own sun, a mere bagatelle of ninety-three millions of miles distant, and, fortunately for the truth of the deductions we may make from it as to the surface behavior of stars in general, a respectable, run-of-the-mill, middle-aged star, neither very hot nor very cool as stars go, and neither a giant nor quite a dwarf among its millions of brother suns. The entirely average position of our sun as to size, luminosity, mass and other characteristics thus facilitates and makes more probable any deductions we may wish to draw from it in application to more distant suns. To repeat, any study of the stars of our universe must start with and be based upon a study of our nearest star—the sun.

About twelve years ago the writer, with two most helpful colleagues—Judge Henry S. Hulbert and the late Francis C. McMath, my father—decided that a fallow and hitherto neglected field lay invitingly open for research through the application of the motion picture to such astronomical phenomena as exhibit rapid motion or change. A small, but most completely equipped telescope was designed and built for the highly exacting technique of the motion picture as applied to astronomical photography, and this installation was located at Lake Angelus, about five miles to the north of Pontiac, Michigan. The instrumental equipment was gradually augmented and improved through several years of gradual evolution and development, too long and too technical to detail here, and in 1931 the plant, under the name of the McMath-Hulbert Observatory, was deeded by its founders to the University of Michigan.

Our initial aims were frankly educational. We envisaged the manifold assistance that carefully planned astronomical films would give to the work of astronomical instruction in schools and colleges. How much more effective it would be, we reasoned, to project for a class a three-minute film, showing, for example, the rotation of the planet Jupiter on its axis and the revolutions of its moons about the planet, than merely to lecture to a class that such things were

happening. Many thousand feet of such educational films were taken by the McMath-Hulbert Observatory of planets and their satellites, the phenomena of sunrise and sunset on the slowly rotating moon, and similar subjects, and a considerable number of educational reels of such types have been shown to scientific societies and distributed to schools and colleges.

It is with a feeling of some regret that we have had to drop most of our efforts to provide purely instructional adjuvants for astronomical teaching—we hope only temporarily—for we are still firmly convinced as to the great value of such astronomical films for the instructor as well as for the student.

The reason for this temporary abandonment is comparatively simple; it has come about merely because a further extension of this motion picture technique to that nearest star we call the sun has opened up such new and astonishingly inviting fields of scientific research that we have been compelled, willy-nilly, to devote every waking moment to a new and fascinating field of most useful scientific work on the sun—the actual depiction of the storms around sun-spots, and the intricacy of the motions of the mighty gaseous prominences that rise for many thousands of miles above the solar surface, and move and change and disintegrate with speeds that range from a few miles per second up to explosive velocities of several hundred miles per second. The many puzzles which are exhibited by these new pictures, some of which remain as yet unsolved, force us to the conclusion that our initial purely educational aim must give ground for the present to a program of pure scientific research.

There are several respects in which the new motion pictures of solar phenomena are unique, and we may be pardoned for assembling certain of their outstanding characteristics at this point.

(1) These pictures are in a very real sense "modern," inasmuch as the first solar films taken with the new McMath-Hulbert tower telescope were made on July 2, 1936, one day after the completion of the tower.

(2) They are definitely unique, because no other installation at present exists which has the instrumentation for similar motion picture records of solar phenomena.

(3) They were the most nearly *continuous* records of solar phenomena ever made, and in this factor, as will be noted below, lies perhaps the largest portion of their value as scientific documents for research purposes. Photographs of the solar surface in white light, and spectroheliograms of solar prominences in the light of calcium or hydrogen have been taken for several decades, but most of these were effectively "stills," to use the terminology of the motion picture studio. Such stills, taken at time intervals of an hour or less, have given valuable data as to the changes occurring in solar features; the continuous character of these new records shows, however, the changes *as they are taking place,* and not only make possible a more detailed study of the mechanisms underlying the phenomena, but also have brought to light a mass of new details, hitherto unsuspected, and unrecorded in the still pictures of the past.

There are in the world to-day seven tower telescopes for studies of the sun; that at Lake Angelus is not only the most recent, but embodies many refinements of design. This instrument may be succinctly described as a telescope which remains fixed in a vertical position, with an arrangement of motor-driven mirrors at the top of the tower, termed a coelostat, to follow the sun as it moves across the sky and to throw its image vertically downward; the Lake Angelus instrument is approximately fifty feet in height. The various mirrors in this optical train are of pyrex, which is peculiarly fitted for solar instruments because of its very low coefficient of thermal expansion. These mirrors are covered with a thin coating of aluminum, deposited by evap-

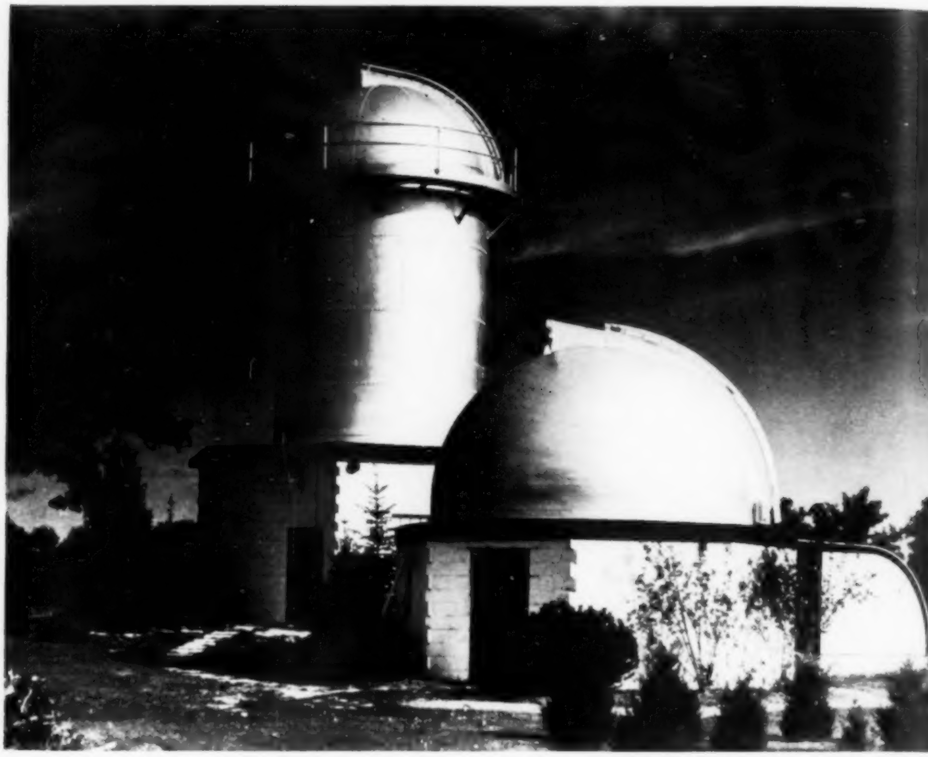
oration in a vacuum; due to this use of mirrors rather than lenses, we have an achromatic telescope that is exceedingly rapid photographically. For this reason, the exposures with the Lake Angelus apparatus may be made very short; exposures on solar prominences in current work range from ten to thirty seconds, where most other installations must count their exposure times in minutes rather than in seconds; such short exposures make for a record that is practically continuous.

At the bottom of the tower the solar image formed by the mirror train falls upon the slit of a spectroheliograph. This rather technical instrument may be briefly described for the layman as a spectrograph which passes the light from the solar image through a narrow slit and then through a lens to a grating or prism which is located in a heavy rotatable steel cage in a well thirty-five deep beneath the tower. The grating disperses and spreads out the light in the form of a spectrum and reflects this spectrum through the same lens back to the upper end. Here a second slit is installed that is the "heart" of the apparatus. With this second slit we pick out some one particular wave-length of some element in the solar spectrum and *throw all the rest of the solar light away*. Solar prominences, for example, are particularly rich in the elements calcium and hydrogen. Thus we may pick out one definite wave-length of calcium and secure a photograph of a narrow strip of the sun where the solar image falls upon the narrow slit, *in calcium light only*, where an ordinary photograph in "white" light would show nothing, because of the overpowering brilliance of the light coming from other chemical elements in the sun. But a photograph of a narrow strip of the sun in calcium light would be useless and almost meaningless; what we need is a calcium or a hydrogen light picture of a considerable area, either of the solar disk itself or of an area at the solar limb where some large prominence is seen in profile. To secure such a picture of an area, the first slit is moved back and forth over the chosen area of the solar image and the second, or "picking-out" slit is given a precisely equal but exactly opposite motion, so as always to receive the calcium wave-length of the spectrum reflected from the grating, and that wave-length only.

The result of this scanning process, performed twice a second, is a calcium or a hydrogen picture of an area. Some other elements may be selected as well, in case we wish to secure an iron picture or a helium picture, and all these pictures in the light of some chosen element would ordinarily be entirely invisible, but are made possible only by this process of sorting out a definite wave-length and discarding all the rest of the light from the sun.

The above brief and schematic description, manifestly, can give but a slight idea of the actual complexity of the apparatus, some conception of which may be derived from the fact that there are about forty small electric motors scattered over the tower mechanisms from the coelostat at the top to the grating cage down in the well, and each of these is controlled by its individual push-button. In these respects the present installation is doubtless the most convenient in existence, as the observer at the spectroheliograph head can perform any adjustment or manipulation without leaving his station, merely by pressing an electric push-button.

The apparent complexity of certain features of the mechanism of this tower telescope is, in some senses, merely a necessary consequence of the exacting technique that has been found indispensable for the taking of satisfactory motion pictures of this and other celestial phenomena. A "run" or "scene" may comprise anything from a few hundred to over a thousand separate pictures on the film; the word "frame" is customarily used for these individual pictures; six or eight hours of continuous work



Photograph by Sidney D. Waldon
THE McMATH-HULBERT OBSERVATORY OF THE UNIVERSITY OF MICHIGAN

will ordinarily go into a run comprising a thousand separate frames.

Manifestly, all the frames of a scene must be as perfectly registered as possible, to avoid flickering and unsteadiness on the screen. Early in the work on the moon and planets that preceded this solar work, it was found that no existing form of telescope drive gave sufficient accuracy. Accordingly, merely as a by-product of the larger program, and after four other methods had been tried and found wanting, a new and improved form of telescope drive was devised, based upon an infinitely flexible and instantly variable control of the input electrical frequency to the telescope drive motor, secured through resistance-ballasted thermionic tubes. This form of telescope drive is known as the McMath-Hulbert electric drive; it brings it to pass that the telescope becomes an automatically *following* instead of a manually *guided* apparatus; it has since been adopted for the drive of the McDonald reflector in Texas, for three telescopes at Lick Observatory, and is under consideration for other projected large telescope mountings. The instruments at Lake Angelus were also the first to employ a similar accurately controlled drive in the declination component, in addition to the ordinary motion given in the right ascension coordinate.

In the astronomical motion picture technique, it must also be possible to arrange for any probable desired duration of the actual expsure, as well as for the duration of the "dark time" between exposures. A gearing train in an underground control room adjacent to the tower makes possible the selection of these times and controls the shutter of the special motion picture camera. A

description, or even a bare tabulation, of all the necessary mechanical details is, however, manifestly impossible in a general article. Only one additional desideratum may be noted. The hundreds of separate frames in a scene would have scant scientific value as records of motion and change if accurate timing arrangements were not provided. Accordingly each individual frame automatically makes a record of its time electrically on a continuously running chronograph in the underground control room.

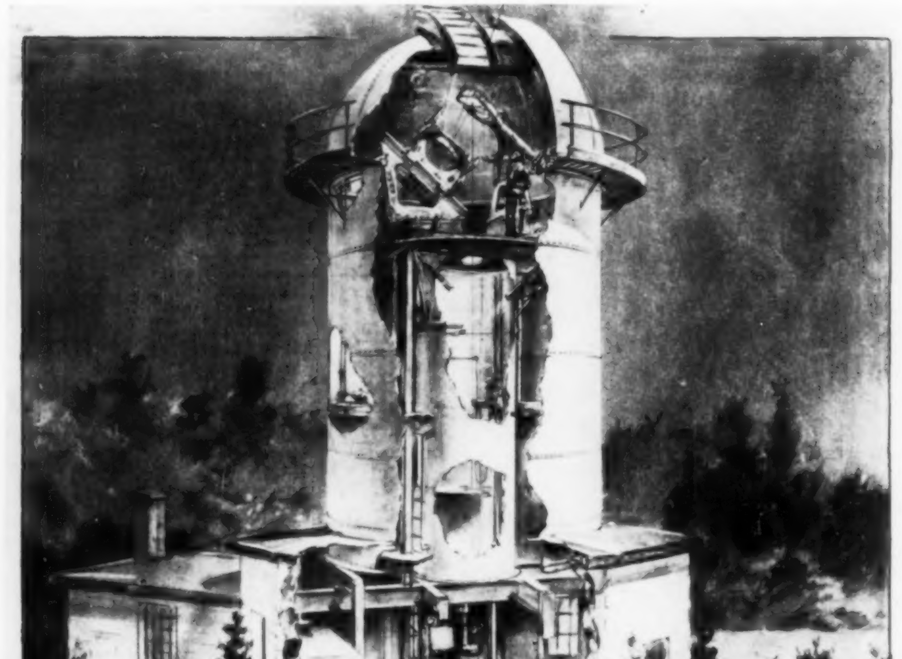
With an exposure of twenty-seven seconds on a solar prominence and a dark time of three seconds, two frames will be taken per minute; they will be projected on the screen at the customary rate of sixteen per second, or 960 frames per minute. Thus it will be evident that the projected picture will have a "compression factor" of 1:480. Such a compression of the record is not only inevitable, but a very distinct advantage, rather than a detriment.

Suppose, as is not at all unusual, that a bright knot is seen to form 100,000 miles above the solar surface and then to descend at the rate of 40 miles per second, about average as solar prominence velocities run, but still 80 times the speed of a high-power rifle bullet. Its total time of descent to the sun will be forty-two minutes. Instead of having to wait that long in our seats to see the history of this descending knot, the above compression factor of 1:480 reduces it to about 5 seconds, and a scene which is made up of several such knots in motion will occupy the very convenient interval of 20 or 25 seconds and appears practically continuous in its record of motions and changes.

By design, considerable space has here been given to an outline of the technique of the motion picture as adapted to an astronomical end, and the apparatus necessary for the purpose, in order to emphasize, not only the more difficult features of the research on its mechanical side but also the unique character of the resulting record.

During the seasons of 1936 and 1937 over ten thousand feet of standard 35 mm film have been exposed in the new tower telescope on the solar prominences or on features of the solar disk itself. Even though every possible mechanical convenience or electrical adjustment has been provided, and even though this tower telescope has been pronounced to be the most rapid, flexible and convenient in existence, the total amount of labor and attention involved in taking over one thousand separate photographs in the run on a clear day which may extend from 8 A.M. or earlier till 6 P.M. is very considerable. It is a pleasure to make acknowledgment at this point to my two colleagues and to those who have assisted in the somewhat complicated technique of solar prominence photography and measurement—to our research associate, Dr. Edison Pettit, of the Mount Wilson Observatory, and to Harold E. Sawyer, assistant astronomer, and John Brodie, assistant, in the McMath-Hulbert Observatory; others have given assistance for shorter periods. We owe also a special debt of thanks to Dr. Heber D. Curtis, director of the observatories of the University of Michigan, who has, from its very inceptance, given every encouragement to this program of solar research and every assistance within his power.

These films, when projected under proper conditions, show scenes of unexampled grandeur, and radically change our preconceived notions of the surface of a star. Though we knew from the "still" photographs of the past that the sun's surface was marked by constant activity as manifested by those solar storms called sun-spots, by the flocculi and by the prominences, these films for the first time bring to us the actual motions in a continuuous record, which we may repeat as often as we need for our scientific studies. These motion pictures very effectively change our conception of



Drawing by Russell W. Porter

THE 50-FOOT TOWER TELESCOPE OF THE McMATH-HULBERT OBSERVATORY.

a star's surface from something at least relatively static to a picture that is intensely kinetic; we begin to realize that the surface of a star is an unending maelstrom of motions due to titanic forces whose precise nature can not as yet be regarded as completely explained.

Even though we are astronomers, we are very human, and we too derive much the same pleasure as does the layman who

sees these films and is enthusiastic in his praise of them, viewed merely as inspiring spectacles. And yet, strange as it may seem, we who are taking and studying these new records of solar activity take rather amiss the enthusiastic praises we hear from laymen or from scientists in other fields who apparently regard them as merely interesting "movies." We feel quite strongly that the magnificence of these displays is, in many respects, only a very secondary consideration in our evaluation of these pictures as scientific records, from which facts of very definite value are being derived as to the actual nature of the surface of a star.

"Conflagrations," explosions, skyrocket sheaves of light like the grand finale of the 4th of July celebrations of our boyhood, are all admittedly inspiring when we realize the tremendous speeds that are actually involved, the temperature of more than 10,000° Fahrenheit, that our picture embraces an area 150,000 miles high and 200,000 miles wide, and that our earth would be but a small disk on the same scale and quite unimportant in comparison to the mighty flames and streamers of incandescent gas that form these solar storms. Yet to us the motions and laws of motion that we are deriving and the nature of the mysterious forces that seem eternally operative on the surface of a star are much the more important considerations as we view these new films.

This new method of attack on the problems exhibited by the surface of a star is still too youthful to permit of explanations of each and every phenomenon observed. Fresh puzzles too frequently show themselves in each run on a new and active prominence, and if the history of our past work is any criterion, the coming season of 1938 will bring to light as many new features as have those of the two preceding years. The complexity of some of the more active prominence displays frequently baffles description, and we often find that the only way to be sure of all that is taking place is a repeated showing of the film; frequently we will notice some minor peculiarity or puzzle in the tenth or twelfth showing that had previously escaped us and had, of course, never been suspected in the still pictures of the past.

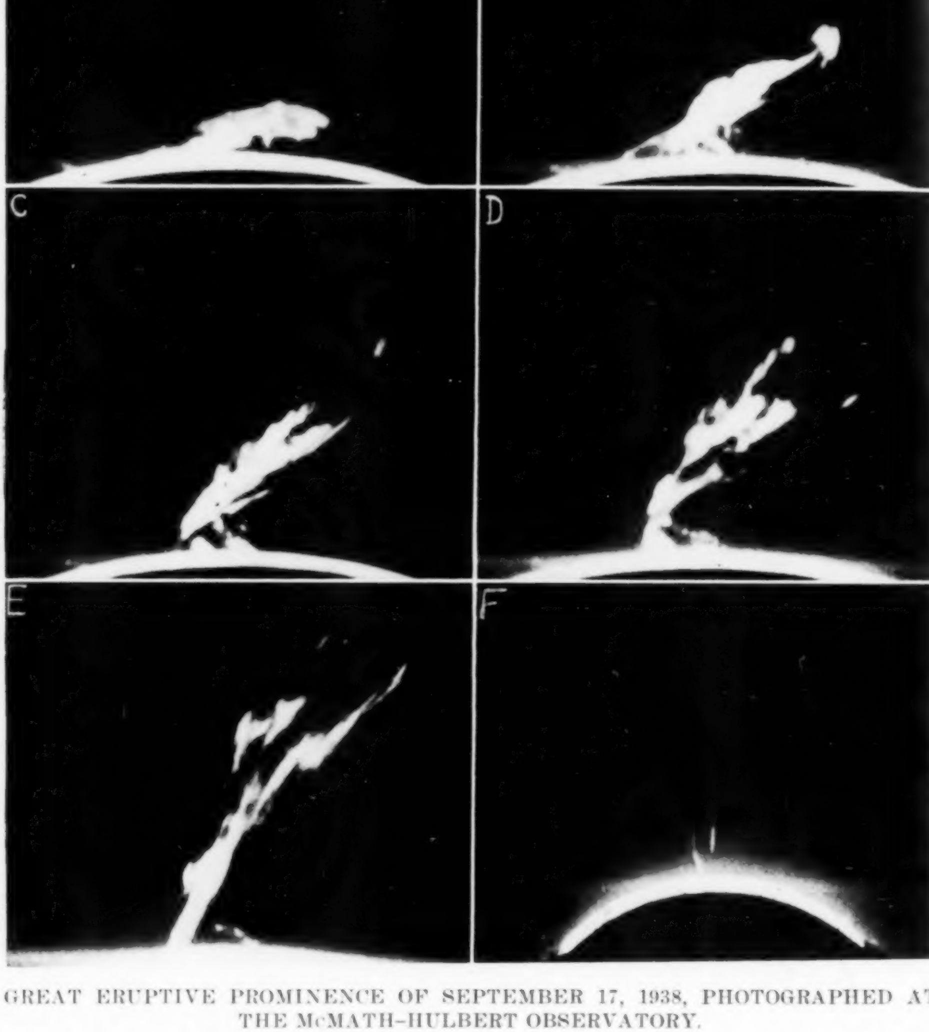
While, as already noted, we are still working on many of the puzzles presented, and are withholding a more precise formulation of hypotheses till more data have been collected, some of the results of the work on the sun with the new tower telescope and our improved motion picture technique may be assembled as follows, either in more general statements or in descriptions of isolated phenomena.

(1) It has become necessary to add three subdivisions to Dr. Pettit's accepted classification scheme for solar prominences, to include three new types of prominence whose existence was not hitherto suspected. These are:

(a) *Surges.* These are very short-lived prominences like spear-heads of flame, that stab upward 1,000 to 10,000 miles or so from the solar chromosphere and as rapidly subside again, with a total life period of only a few minutes. As seen in profile in runs on prominences, the limb of the sun will occasionally exhibit an almost continuous activity of this type. In pictures of the solar disk proper, the sudden short-lived splotches of brilliant light that appear and disappear in areas about sun-spots are believed to be these same surges, seen from above.

(b) *Ejections.* This name has been given to the balls of luminous chromospheric matter thrown out of sun-spot areas like Roman candle displays. They are relatively faint and seem to leave the sun without returning. In one or two cases these balls seem rather more like hollow spheres or perhaps in the form of smoke rings; it is difficult to decide with the material now available.

(c) *Coronal type streamers.* These



GREAT ERUPTIVE PROMINENCE OF SEPTEMBER 17, 1938, PHOTOGRAPHED AT THE McMATH-HULBERT OBSERVATORY.

A—$14^h50^m.69$; B—$14^h55^m.84$; C—$15^h06^m.13$; D—$15^h09^m.11$; E—$15^h14^m.31$; F—$16^h06^m.7$ G.C.T. EXPOSURES A TO E WITH 20-FOOT FOCUS MIRROR, F WITH LENS OF 74 INCHES FOCAL LENGTH. IN F THE PROMINENCE GOES OUT OF THE PICTURE 1,000,000 KM ABOVE THE SUN.

are very puzzling. In such streamers matter appears to form, or more properly to become luminous, at an altitude of 120,000 miles or more above the surface of the sun and then to descend in successive streamers to the solar surface.

These coronal streamers are generally rather faint and have never been detected before.

(2) Several very interesting examples of *violently eruptive* prominences have been recorded. For one of these, taken in September, 1937, though the entire period covered by the scene was only 80 minutes, the upper portions could not be kept within the motion picture frame in spite of three successive changes to shorter focal lengths; the total height was about 620,000 miles, which held the world's record until the recent record of 900,000 miles for a prominence photographed at Mount Wilson. The velocity of this Lake Angelus prominence reached 432 miles per second; as this is considerably greater than the "velocity of escape" under gravitational attraction at this distance from the sun, this is believed to be the first recorded instance where we have observed matter shot out into space beyond the sun's attraction, though such possibilities have long been recognized in theory.

(3) *Arch types.* Several great arches of unusual interest have been recorded. In one of these it was nearly 100,000 miles between the "feet of the rainbow." Though there was no noticeable accretion of material at the top of this arch, luminous knots of gas are observed continuously descending to the sun in *both directions* from the summit of the arch. Why?

(4) *Predominance of matter in descent.* Even if we include the prominences of eruptive type mentioned under (2) above, perhaps 90 per cent. of our prominence scenes record matter in descent only. On a number of great "banyan-tree" prominences, with multiple stalks or trunks connecting the enlarged upper portions to the chromosphere, bright nodules of matter will be observed spiralling downward along the "trunks." We have mentioned above under (1), (c) the growth luminescence in, or actual formation of faint clouds high above the sun, from which the coronal type streamers descend, phenomena which seem to necessitate the postulation of some form of solar chromospheric atmosphere intermixed with the corona.

Much the same class of phenomena are exhibited in lower bright streamers of the beautiful "set-pieces" of a fountain type; the motion of descent is here often clear and rapid; any corresponding ascent of matter on a possible rising arm of the complete trajectory is either very much fainter or entirely absent. Astronomers who see these films for the first time frequently attempt to explain this curious phenomenon by ascribing the invisibility of the ascending side of the streamer to the Doppler effect, arguing that some velocity in the line of sight moves the wave-length under observation "off the slit" for the ascending branch and implying that these films give a partial rather than a true picture of these motions. We are utterly unable to accept this explanation in the vast majority of cases, for we have noted only two cases of sudden brightening of small patches near the chromosphere that may possibly be due to the Doppler effect, that is, to a velocity in the line of sight sufficient to bring a different wave-length and hence a previously unobserved detail into the slit of the instrument. But an elementary consideration of the geometry of these prominence arches would predicate roughly equal velocities in the line of sight for matter at corresponding portions of the hypothetical ascending or the descending branches of the arch. Moreover, although workers in the past have maintained that narrow slits are an inescapable necessity in spectroheliographic work, we have, as a result of numerous experiments with wider slits, taken beautifully clear and sharp spectroheliograms in the H alpha line of hydrogen with *both* slits 0.5 mm (about

one fiftieth of an inch) in width. This width would necessitate a difference in radial velocity of about $\pm$ 110 kms per second (68 miles per second) to move a portion of our picture off the slit and thus render some parts invisible. While higher velocities are occasionally observed in eruptive prominences, such velocities have only rarely been found in these arch trajectories.

The phenomenon remains a puzzle. It is apparent that what goes down very probably came up, but why should the upward journey be predominantly invisible? Is it that the gases on their upward path are in some different temperature or ionization state, changing back to another and photographically recordable state soon after passing the crest of their trajectory? Data are being collected that may eventually give an answer to this pressing and difficult question.

(5) Previous work had detected *no motions* within the *dark* hydrogen flocculi. We have been fortunate enough to "catch" and to photograph for a total elapsed time of 5½ days an enormous hydrogen flocculus whose total length must have been of the order of 700,000 miles, extending over a considerable portion of the solar disk. Its internal motions and its final disintegration were clearly recorded. So far as is known, this is the first case where the life-history of one of these dark hydrogen flocculi has been followed from its first appearance to the end.

(6) Abundant confirmation has been secured in the study of motions in prominence streamers in support of the curious *laws of prominence motion* discovered earlier by Dr. Pettit. The velocity of a prominence or prominence formation is uniform, increasing suddenly at intervals. When there is a change in velocity the new velocity is generally a simple multiple of the previous velocity. That is, a knot that has been moving along a streamer, at a uniform speed of, say, 21 miles per second will suddenly (sometimes in less than a minute) be accelerated to a uniform speed of 42 miles per second, without any apparent transition through intermediate velocities. This puzzling phenomenon has been studied and extended to include nearly all prominence types at Lake Angelus. Like some others found in the Lake Angelus work mentioned above, it shows that we have many still unknown factors with which to deal before we can secure an explanation of all the laws that govern the motion of gaseous matter near the surface of a star.

Such, then, are some of the results, as well as some of the problems, that are growing out of the application of this new technique to the study of a star's surface behavior; the work is being continued as fast as time and money will permit. The very richness of the material being secured has its embarrassing features; it will easily be seen that the detailed measurement of the motions even in one tenth of the frames of a prominence picture that includes over a thousand separate pictures involves a great deal of time and not a little calculation. The number of the prominences, as well as the number and the activity of the flocculi and other disk features, shows an intimate connection with the curve of the number of sun-spots that reaches a maximum roughly every eleven and a third years. We have recently been passing through a period of maximum sun-spot activity, but we do not yet know what detail changes in prominence activity will be observed on our films at a sun-spot minimum. We are inclined to predict that while we shall then have fewer prominences on which to work, they still will be of equal value in formulating theories of the surface layers of a star. Certainly only a beginning of our program of research will have been made until we have worked completely through at least one sun-spot cycle.

THE HIGHEST ERUPTIVE PROMINENCES

By Dr. EDISON PETTIT

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PROMINENCES on the sun may be classified into active, eruptive, spot-type, tornado and quiescent. Seen on the disk of the sun quiescent prominences look like ragged ribbons, which indeed they are, standing on edge. Representative dimensions are 10,000 km thick, 200,000 km long and 50,000 km high.

The outward form of these quiescent prominences changes slowly, but usually the change from hour to hour is unmistakable. The internal structure, on the other hand, is in constant turmoil. Velocities of 10 to 20 km/sec are common among the knots and streamers of which they are composed.

Just how these prominences make their appearance is still something of a mystery. I think the usual assumption is that they rise directly out of the chromosphere, for they are commonly attached to it by connecting streamers or strips; but unfortunately for this idea, what motion we have been able to detect by cinematography at the McMath-Hulbert Observatory, is downward to the chromosphere. It must be admitted that at present we know nothing of the formation of these objects. Their destruction, on the other hand, we have witnessed on a number of occasions.

Usually the destruction of one of these prominences proceeds as follows. A center of attraction or a sun-spot forms nearby and begins to pull streamers from the prominence. A center of attraction is not marked in any way on the chromosphere; and we suppose it to be a local electrical charge, since it may occur anywhere on the sun's surface. Ordinarily the activity increases, and broad ribbons of material are pulled off. These ribbons arch upward, the whole prominence rises, swings through a wide arc and is sucked into the chromosphere.

As this attraction of the center or spot increases, the prominence rises higher, three or four hundred thousand kilometers, before being pulled back into the chromosphere. We observed one such case at Lake Angelus on July 24, 1936 (Plate I). When the intensity of the field of attraction reaches this stage long, slightly curved streamers, not associated with the prominence, are sometimes seen entering the center of attraction or spot from outside space. These we have called *coronal* prominences and they were discovered by the motion-picture method at Lake Angelus.

When the force from the center of attraction or sunspot reaches a certain critical value the prominence rises and leaves the sun entirely. These prominences we call eruptive. Thus it is seen that quiescent prominences become associated with the eruptive, through their conversion into active or sun-spot prominences. So far I have never seen a tornado associated with an eruptive prominence.

The earliest published account of an eruptive prominence, which included measurements of height, was by Trouvelot based on observations made at the Meudon Observatory (France) on August 16, 1885, by the wide-slit spectroscope method. This prominence rose from an initial height of 172,000 km to 416,000 km in two hours. Another, observed by Fenyi on September 20, 1893, at the Haynald Observatory (Hungary) with similar equipment, reached 501,000 km. These observations were made either by an eyepiece micrometer or, when the prominence occurred far from the north

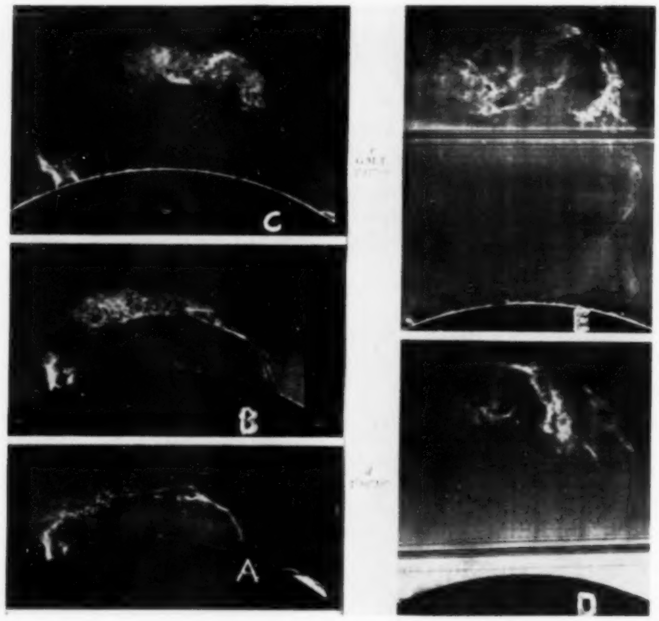

PLATE I. Great eruptive prominence of May 29, 1919, photographed at the Yerkes Observatory. A, $7^h\ 41^m$; B, $8^h\ 57^m$; C, $11^h\ 33^m$; D, $13^h\ 20^m$; E, $13^h\ 57^m$ C.S.T. A sunspot is located near A.

or south point, by stopping the driving clock of the telescope and observing the time interval between the disappearance of the chromosphere and prominence from the field. Fenyi became expert in this latter method.

The first photographic work was done with the spectroheliograph by Deslandres at the Paris Observatory on May 31, 1894. This prominence rose 458,000 km, and one photographed by Hale and Ellerman at the Kenwood Observatory (Chicago) rose 450,000 km, on March 25, 1895. These photographic records stood till Evershed at Kodaikanal (India) photographed one on May 26 1916, that rose 643,000 km from an initial height of 102,000 km in one hour.

Up to this time, 21 eruptions had been observed, mostly by the visual method. One would suppose that something of the characteristics of the motion would have been found, yet the outcome was disappointing. Usually each prominence was observed by an individual, and the eruption had been completed before he realized the importance of a large number of observations. Fenyi, who alone observed many, was convinced that they moved like free projectiles under gravity, in spite of the fact that his observations would not substantiate this idea. Pringsheim in "Physik Der Sonne" thought the observations showed that eruptive prominences rise with erratic motion. Yet, in retrospect we can see that these observations really show both laws of motion found from more precise observations later.

The first real fact of prominence motion was pointed out by Evershed after the eruption of May 26, 1916, when he showed that the velocity increased with the height, although observations were insufficient for critical examination of the velocities.

The eclipse of May 29, 1919, is notable in the annals of science for providing the

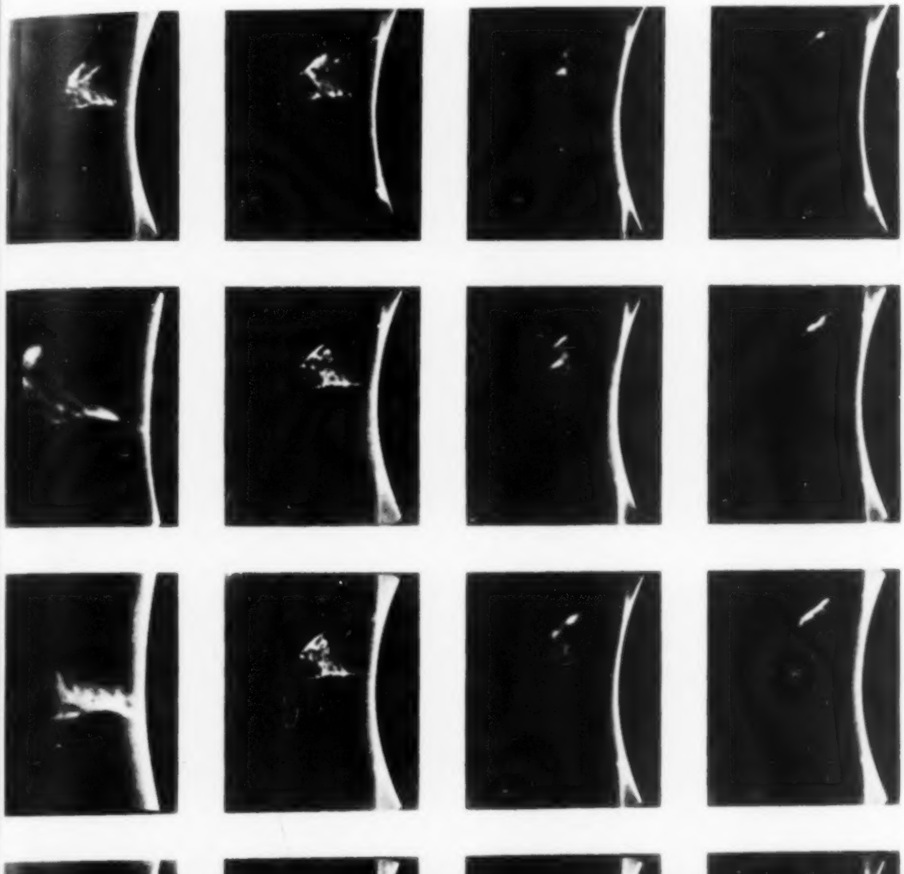

PLATE II. Quasi-eruption of July 24, 1936, taken at the McMath Hulbert Observatory. Exposures 1–4 with 40 foot focus at 1^m intervals. Remaining exposures, 5–20 with 18-foot focus at 6^m intervals.

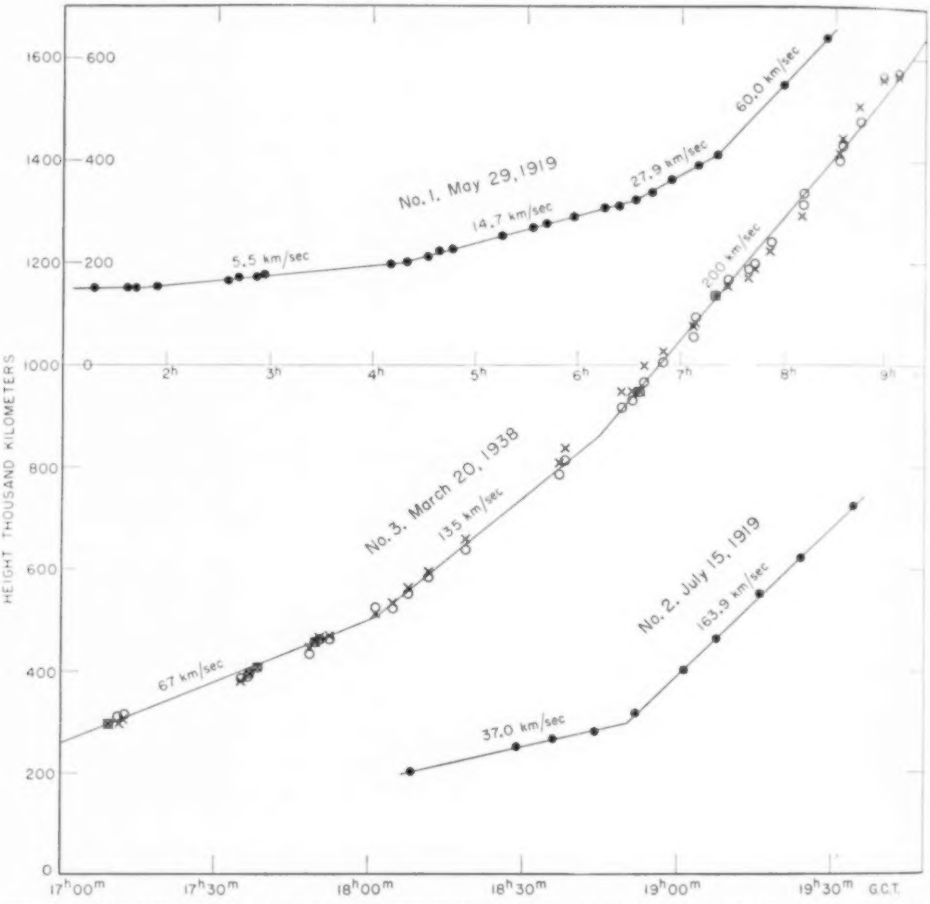

FIG. 1. TIME-HEIGHT DIAGRAMS OF ERUPTIVE PROMINENCES; (1) MAY 29, 1919, (2) JULY 15, 1919, AND (3) MARCH 20, 1938. NOTE THAT THE STRAIGHT LINES INDICATE CONSTANT VELOCITIES WHICH INCREASE SUDDENLY AT INTERVALS.

first positive observational evidence of the validity of the theory of relativity. When the eclipse occurred one of the largest prominences ever seen appeared on the east limb of the sun. The Smithsonian party, located in the Andes Mountains, near La Paz, Bolivia, reported that patches of snow lying on the ground were colored blood red by the light of this extraordinary prominence during totality.

I was at the Yerkes Observatory at this time working on the problem of motions of prominences. This prominence had been photographed with the Rumford spectroheliograph several times since its first appearance on March 22. On May 28 it appeared as a very large object, full of streamers. In those days the observatory operated its own power plant, and Professor Frost arranged that it should start early next day and the rising floor should be left at its highest point in the 40-inch dome, so we could start changing to the spectroheliograph with the least loss of time.

May 29 was a remarkably clear, warm day, favorable to solar observations. One of the difficulties we encountered was from gossamer from the cottonwood

trees, which filled the air at that time of year and had to be brushed from the spectroheliograph slit continually.[1] The prominence rose slowly at first, but continued to rise through the entire morning, and for seven hours I followed it till it faded from view.

This prominence (Plate II) rose from an initial height of 200,000 km to 760,000 km, exceeding a solar radius and was the record height for that time. Plate I shows five exposures. The first, taken near eclipse time, shows the prominence pouring into a small sun-spot located at A. Note the streamers which continue to return to the chromosphere throughout the eruption. This phenomenon is common to eruptive prominences.

With this prominence it was possible to determine the center of gravity of the floating cloud with some accuracy, as well as the maximum and minimum heights. On plotting the heights of the prominence against the times of observation (No. 1, Fig. 1), much to my astonishment, it appeared that the observations were represented by four straight lines and that the prominence rose with uniform velocity, increased at intervals, as if by an impulse of very short duration.

Another prominence was observed with the same instrument on the following July 15, resulting in plot No. 2. Further confirmatory evidence was found in a prominence observed through clouds on September 1, 1919, but the data were too scattered to be definitive. It was now apparent that this principle of uniform motion, increasing suddenly at intervals, was a general one and a study of all observations made on eruptive prominences up to that time led me to think this was really a law of motion of eruptive prominences.

It was also noted that each velocity in the prominence of May 29, 1919, was a small whole multiple of the preceding velocity, but the two velocities in the prominence of July 15, which I regarded as being quite accurate, did not follow this principle; in fact, the ratio was nearly 4.5, so this idea had to be given up.

On October 8, 1920, Lee at the Yerkes Observatory, photographed a prominence which rose from 110,000 km to 831,000 km in $5\frac{1}{2}$ hours, which held the record for prominence heights until November 19, 1928, when Royds at Kodaikanal photographed one which rose from 364,000 to 928,700 km in $1^h\,18^m$. These also verified the first law.

With the advent of our greater knowledge of atomic physics and radiation several theories based on light pressure were proposed to explain the motions of eruptive prominences. All these theories, however, required continuously accelerated motion and thus did not agree with the observations. I therefore returned to the 40-inch telescope in 1930 to secure additional data of a more detailed kind. On August 6, 1931, an eruptive prominence was secured that rose from 49,000 to 620,000 km in four hours. Exposures were made with an average interval of 4.8 minutes, which gave a very definitive velocity determination. Measurements made by three observers independently, and by myself, showed that the first law of motion was unquestionably verified in detail and that the changes in velocity occupied a time interval of the order less than five to ten minutes.

Obviously, the proper way to study such phenomena as eruptive prominences is by cinematic photography. About this time the McMath-Hulbert Observatory at Lake Angelus, Michigan, undertook to solve the problem of its application and secured successful films of the moon,

[1] This fine thread-like and transparent material is not affected by the intense radiation in the solar image formed by the 40-inch objective which will set a stick of wood afire. I once set the spectroheliograph on the sun when a spider had spun his web over the slit frame. When the solar image moved upon the slit the spider went up in smoke, but the web was unaffected.

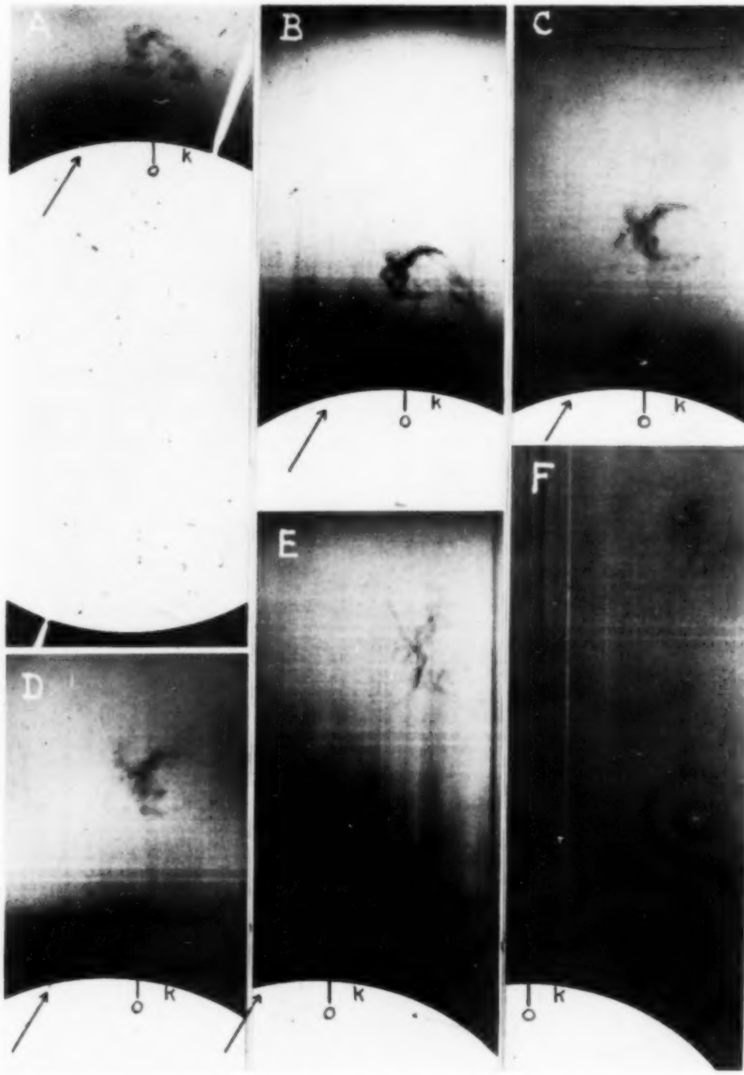

PLATE III. Eruptive prominence of March 20, 1938, taken at the Mount Wilson Observatory, which reached the record height of 1.11 solar diameters. (A) $9^h\ 12^m$, prominence near N pole of sun, streamer pouring into center of attraction K. (B) $9^h\ 35^m$, (C) $10^h\ 00^m$, and (D) $10^h\ 18^m$ also show streamer. In (D) prominence is already a half solar diameter high; (E) $11^h\ 03^m$ it is 0.8 and in (F) $11^h\ 31^m$ it is 1.1 solar diameters high.

planets and Jupiter's satellites with a $10\frac{1}{2}$-inch reflector. After experiments with a spectroheliosccope attached to the telescope and adapted to motion picture photography, it was decided to build the present tower telescope, designed for taking motion pictures of solar phenomena and prominences in particular. In 1936 a quasi eruption, a sort of *missing link* between the true eruptions and active prominences, was observed on July 24. Plate II shows 20 stages of this object.

This prominence nearly got away from the sun, but the center of attraction finally brought it back.

On September 17, 1937, an eruptive prominence was secured by Sawyer and Brodie at Lake Angelus, which was followed till it left the frame of the motion picture camera at 1,000,000 km above the sun. This also had the highest velocity, 728 km/sec, ever observed in a prominence. Even at 1,000,000 km it was still sending streamers back to the sun.

The reader will probably say that this record might stand for some time; but matters move rapidly in science. Plate III shows the eruptive prominence observed by J. O. Hickox at Mount Wilson on March 20, 1938, which reached the unprecedented height of 1,550,000 km, or 1.11 solar diameters above the sun. This prominence was almost at the north pole of the sun; that of Deslandres in 1894 was near the south pole. This puts prominence material definitely in the region of the outer corona.

Now it will be interesting to look at some of the best-determined velocities for a moment. Table I shows five prominences for which the velocities could be called definite.

TABLE I
THE RATIOS F OF SUCCESSIVE VELOCITIES V_o OBSERVED IN ERUPTIVE PROMINENCES

Date	V_o (km/sec)	F
May 29, 1919..	5.5, 14.7, 27.9, 60.0	3, 2, 2
June 18, 1929..	3 , 19 , 37	6, 2
Nov. 14, 1934..	13.5, 40	3
Sept. 22, 1935..	2.2, 32.5, 130	15, 4

Note that each velocity V_o is nearly a whole multiple F of the preceding velocity. A survey of all the data to 1935, a period of 50 years, showed that the great bulk really followed the principle that after increase in velocity the new velocity is a small whole multiple of the preceding velocity. This was called the second law of prominence motion. For instance, Lee's prominence of October 21, 1914, gave 7, 22 and 43 km/sec; and Fenyi's of November 16, 1892, gave 4.4, 6.6, 28.3, 57.2 and 115.0 km/sec.

However, there is a group of prominences for which the observations are among the most definite, which obey the second law, save for the last velocity. These are collected in Table II.

TABLE II

Date	V_o (km/sec)	F
Aug. 6, 1931....	5, 19, 74, 126	4, 4, 7
Sept. 17, 1937....	28, 58, 186, 540, 728	2, 3, 3, 4
Mar. 20, 1938....	67, 135, 200	2, 3

Here it will be seen that the last velocity reverts to a whole multiple of the one preceding the changed velocity (underlined in the table). The corresponding multiples F are underlined in the table.

Now we can explain some apparent exceptions to the second law among prominences previously observed, including that of July 15, 1919, of which we have already spoken. The observations of these prominences began when the eruption was already under way and the prominence already 200,000 km or more above the sun. We may expect, therefore, that there may have been a change of velocity before the observations began, and the first observed velocity must be a small whole multiple of it. This we introduce in parentheses in Table III.

TABLE III

Date	V_o (km/sec)	F
July 15, 1919	(18.2), 37.0, 163.9	(2), (9)
June 23, 1924	(14.5), 43 , 73	(3), (5)
Nov. 19, 1928	(40) , 81 , 200	(2), (5)

These hypothetical velocities, then, bring the residue of our well-observed prominences into line with the second law, as modified in Table II.

The reader will now wish to know what makes these eruptive prominences move

in this odd way, for uniform motion over great distances in a gravitational field is hard to understand. Matters are even more complicated for the streamers and knots pulled off from prominences by centers of attraction and sun-spots obey the laws of motion of eruptive prominences, but move in the reverse direction along curved lines. Moreover, eruptions do not always move in a vertical direction, but sometimes at angles of 40° or 50° to a solar radius. The prominence of March 20, 1938, moved at an inclination of 25° to the radius.

Does this material, which is essentially chromospheric in nature, come back? Maybe the coronal prominences are the answer, but that is a guess. No, light pressure has not satisfied the observations; probably we do not know how to apply it to the problem. If we make the most rational assumption, that the energy absorbed in the spectrum (so-called "resonance absorption") is all that is converted into pressure, there is not nearly enough for hydrogen, which is over 97 per cent. of the mass, since we suppose that the proportion of excited atoms is only 10^{-11} of the whole. We must speculate that the Lyman alpha line is 10^{-8} times as bright as the photosphere over the same spectral range, one angstrom, to get the necessary energy.

Some color is lent to this idea by radio fade-outs; they occur only on the daylight side of the earth, hence the ionizing agent is high-frequency radiation and, since we can not photograph it, the wavelengths must be shorter than the atmospheric transmission limit λ 2897. We really ought to get a rocket outside the atmosphere to photograph the solar spectrum. It is perfectly feasible and the problem deserves a concerted effort for its accomplishment by a laboratory dedicated to this study. We may have to give the rocket a boost with a piece of naval ordnance to conserve the great energy loss now sustained by it in getting under way, and this will raise problems of designing optical equipment which will stand the enormous acceleration involved, but these are also details which are perfectly solvable.

THE FLOTATION OF MOUNTAINS

A THEORY OF OROGENESIS

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PRIOR to the middle of the nineteenth century a great trigonometrical survey was in progress in India which included the Himalaya Mountains. In the course of the survey it was observed that differences of latitude determined by triangulation did not check with the differences measured astronomically, for the same pairs of stations. The discrepancy was most marked in the vicinity of the south flank of the great Himalayan range; and was finally interpreted as due to deflection of the plumb line by the gravitative attraction of the mass of the mountains. The amount of discrepancy between two stations on the same meridian and about 5°23′ apart in latitude was 5.″236. Archdeacon Pratt, an eminent mathematician of the day, undertook to calculate what should be the deflection. The volume of the Himalaya above sea level was estimated from surveys of the relief, and the mean density, based on various determinations of their constituent rocks, was assumed to be 2.75. The result of Pratt's studies was that the differences between the geodetic and the astronomical determinations of latitude should be much larger than they were actually found to be. For the two stations above referred to, where the difference was 5.″236, he showed that the discrepancy should be 15.″885, more than three times as much.[1] He explained this by assuming that the ellipticity of the Indian arc of the earth's profile was abnormally large by reason of the uplift of the mountains. This condition, if real, would have increased the difference of latitude obtained by geodetic measurements, and so harmonized it with that found by astronomical observations.

The problem was taken up immediately by G. B. Airy, the astronomer royal, and was discussed by him in a paper presented to the Royal Society[2] less than a month after the presentation of Pratt's paper. Airy contended that the deflection of the plumb line in the region immediately south of the Himalaya was due to a defect of mass in the mountain range. This defect, he argued, must be due to a relatively low density in the region below the range. The mass of the mountain above sea level having a mean density of 2.75 exercises a positive attraction on the plumb bob; but this is more than offset by the lower density of the roots of the mountain, as compared with the normal density at similar depth, where there are no mountains, as, for example, under the plains of India to the south of the Himalaya. This relatively light rock of the mountain roots was, according to Airy, nothing less than the same rock which appears in the mass of the mountain above sea level. When the mountains were formed by the culmination of growing compressive stress in the earth's crust, there was a downward as well as an upward protuberance of the crushed and folded belt. As the mountains rose the downward protuberance of light superficial rock was pushed down into the heavy rock of the deeper part of the crust, and by the principle of flotation supported the range. Pratt had considered the Himalaya as a range sessile upon the earth's crust, and had referred

[1] *Phil. Trans. Roy. Soc.*, 145: 53–100.

[2] *Phil. Trans. Roy. Soc.*, 145: 101–104.

the deflection of the plumb line to the gravitative effect of the mass above sea level only. Airy was the first to clearly formulate the view that mountains have depth as well as height and that the latter exists by reason of flotation of light rock in heavy. His explanation of the deflection of the plumb line apears, however, to have been anticipated a few years by the Frenchman Petit,[3] who in 1849 wrote on the probability of a defect of mass beneath the Pyrenees; although he recognized that the deflection of the plumb line might equally well be explained by an excess of mass in the earth to the north of Toulouse. Airy's paper cleared up the difficulties of the Trigonometrical Survey of India; for he showed that the discrepancies in the difference of latitude between pairs of stations are due entirely to error in the astronomical method, as affected by the deflection of the plumb line. The geodetic method is unaffected by this deflection, and gives accurate figures for relative geographic position.

The notion of universal crustal balance and the support of mountain ranges by their downward protrusion into heavier rock, so clearly set forth by Airy, appears to have had little or no influence on geological thought for over three decades. In 1889, however, the idea was revived by Dutton[4] in a brief paper presented to the Philosophical Society of Washington, in which, curiously enough, Airy's interpretation of great ranges as floating masses was not mentioned. Dutton recognized that the larger features of the relief of the earth's surface were due to balance of rock of lower density in the elevations by rock of higher density in the depressions; and he called this principle of balance isostasy. According to him the shift of load by erosion causes a depression of the area of deposition and a rise of the area of denudation; and the vertical movements of the crust so induced are accommodated by a lateral viscous flow of the underlying rock. Since the publication of Dutton's paper nearly fifty years ago isostasy has been generally accepted as an important principle of geology. But like many other important principles it has been slow of application. Most geologists are more concerned with the details of their own particular field of work than with the general principles of their science. Important contributions to our knowledge of the subject have, however, been made by Hayford and Bowie, of the Coast and Geodetic survey, by Gilbert, of the U. S. Geological Survey, by Barrell, of Yale University, and by the Trigonometrical Survey of India.

One phase of the geodetic work carried on for many years in various countries of Europe, India, Canada and the United States has to do with the measurement of the force of gravity at many points on the surface. If mountains were supported by the rigidity of the earth and were sessile on a crustal layer of uniform density, their mass would in every case greatly affect the values obtained for the force of gravity at points along the range. The values after correction for altitude, would be quite different from those obtained on low-lying plains, above the same crustal layer. But the actual values obtained, whether on mountains, plateaux or plains, are remarkably the same, except for minor anomalies, which are chiefly due to failure to correct for the geological factor peculiar to the station. In arriving at the figures for the force of gravity at any point on the surface, the values obtained from the pendulum observations are subject to various corrections, such as for latitude, altitude, topography. But there is always another correction that should be made and rarely is, that is for the local density of

[3] *Compt. Rend. Acad. Sci.*, 29: 729–734. 1849.

[4] *Bull. Phil. Soc. Wash.*, 11: 51–64. 1889.

the rocks in the immediate vicinity of the station. Geodesists usually have no knowledge of this factor, and so the correction is rarely made. This accounts in part for the small anomalies or departures from the theoretical or calculated value for the force of gravity. Notwithstanding this, the anomalies are so uniformly small that the conclusion is justified that mountains are not merely masses above sea level sessile on a heavy layer of the crust, but that equally light rock, by far the larger part of the mountain mass, extends down into that layer; so that both upward and downward protrusions are supported by flotation in it. In other words, the geodetic results tend strongly to establish the validity of the principle of isostasy.

There are certain regions where the uniformly small anomalies are of peculiar significance for the validation of the principle of isostasy. These are regions of low relief, or peneplains, where geologists are quite certain lofty mountains once stood. If these mountains in the heyday of their existence had been supported by the rigidity of the crust, either they must have presented gravity anomalies of enormous amount, and so been at variance with the general gravitative balance of the crust, or if they then presented no large anomalies they should do so now owing to the removal of so large a mass. Large anomalies do not occur in such regions to-day, and it is highly probable that they never did. We are thus forced to accept the validity of isostasy.

Perhaps the most striking and convincing instance of the effect of shift of load upon the earth's crust is that produced by the imposition of the ice-sheet on the northern part of this continent in glacial times and its subsequent removal. At the time of this astonishingly recent event in the history of our planet a load was transferred from the ocean to the continental surface in the form of a vast ice-cap several thousand feet thick. The effect of the imposed load was to depress the surface of the land, and when the ice vanished there was a corresponding recovery from the depression. As the ice-cap slowly waned in response to the advent of a warmer climate, its southern front, receding to the north, impounded the drainage which tended to flow in that direction, and a system of vast lakes was thus created having a wall of ice for their northern shore. The other shores were like those of normal lakes of our day. Along these shores distinctive shore features were built, such as cliffs, beaches, bars, spits and deltas, which of course were at the time of their formation horizontal. With the vanishing of the ice and the consequent draining of the lakes, these horizontal shore lines were tilted to the north; and are all to-day far above sea level, notwithstanding the fact that the surface of the ocean must have been raised by the return of the ice-cap to it as water. The inclination of these shore lines is from six inches to a foot to the mile, and they remain horizontal in directions normal to that of the tilt. They are perfectly plain features, many of which have been surveyed and leveled. The tilt is ascribed by geologists without question to the recovery from depression of the continental surface on removal of the load of ice. Here then is an unequivocal case of disturbance of balance of the earth's crust by shift of load, adjusted, both as to depression and recovery, by plastic deformation of the rock in depth.

To the layman, who may be skeptical of the plastic deformation of the firm rocks of the earth's structure, it may be well to say that the effect of flowage in rocks is a phenomenon familiar to geologists. Many rocks, both igneous and sedimentary, are now exposed at the surface by deep denudation, which have been so attenuated by flowage that their

originally equidimensional mineral constituents have been drawn out into thin lenses or spindles.

The most common shift of load exemplified in geological processes is that effected by erosion. The rivers flowing to the sea are burdened with detritus, either carried in suspension or rolled along the bottom, derived from the waste of continental surfaces. This detritus is deposited at the margin of the continents in the form of deltas and other embankments. In geological time the amount of load thus shifted becomes very large. The delta of the Mississippi, built up since Cretaceous time, is 1,000 miles in extent from east to west, is 600 miles across, and has a maximum thickness of about 6 miles. It contains about 1,500,000 cubic miles of water-laden sediment, or about 1,000,000 cubic miles of dry rock derived from a portion of the North American Continent. The shoreward half of this delta is composed of shallow water deposits from top to bottom. In order to accommodate these deposits the original bottom upon which they rest must have been subsiding during their accumulation. This subsidence is reasonably ascribed to the effect of the load imposed, the latter being accommodated by a counter flow of rock in depth from the area of the delta to the continental area being relieved of load by erosion. This counter flow of mass between loaded and unloaded regions is the essence of the idea of isostasy; since that is the only mechanism whereby balance of the adjoining sectors of the earth could be maintained. Equal masses per unit of area are exchanged, one at the surface and one in depth; but the volumes of those masses may be very different. The density of the dry rock removed by erosion from the hydrographic basin of the Mississippi is about 2.67; that of the rock which flows out in depth from below the delta to compensate the added load is probably about 3.3. Every foot of thickness of material, having a density of 2.67, added to the delta will be compensated by the outflow in depth of a layer of equal weight per unit of area but having a density of 3.3 and thickness of .8 foot. It results from this difference of volume between the mass added to and the mass withdrawn from the area of the delta, that the subsidence of the floor on which it rests is slower than the rise of its surface, so that ultimately the upward growth of the delta will come to an end slightly above sea level. But if the deltaic embankment extend out into deep water, as is generally true of large deltas, the subsidence will there accommodate the deposition of many thousands of feet of sediments. According to the principle of isostasy the load thus imposed on the sea floor is compensated by the withdrawal of an equal mass per unit of area, but of smaller volume, and the distribution of this, by flow in depth, to the continental area, which has been relieved of a corresponding load by erosion, thus maintaining gravitative balance.

Another example of shift of load, which is frequently encountered by geologists, is due to the operation of compressive stress in the earth's crust in excess of the strength of the rocks. Where the rocks are massive and strong they yield to this stress by rupture, and the break commonly takes place on a plane inclined to the horizon, often at low angles. On such a plane a large part of the upper crust may be shoved under the adjoining part and so produce the reverse effect of an apparent overthrust. In this way the upper crust may be locally thickened, and the thickening creates an increase of load in the belt affected. Such thrusting is well known along the front of the Rocky Mountains, the west side of the Appalachians, the north of Scotland, the Alps, the Himalayas and other mountains. If the movement be small the additional

load may be supported by the rigidity of the crust, but if it be large, as in the cases just referred to, the disturbance of balance will be compensated by the depression of the belt into the heavy rock of the deeper crust, and the uplift of the surface caused by the thrust will be only a fraction of that depression. The disturbed and thickened belt will virtually float in the heavy deeper rock. If, however, the deeper, heavier portion of the crust be similarly thickened by thrusting, the column so affected will be overloaded, and the only way that balance can be restored is for the excess mass to sink into and merge with the general mass of heavy rock, without upward flotation. The first uplift of the surface, if it endure long enough, may be eroded away and, when the thickened sima flattens out, the eroded surface on subsidence may become that of a structural valley.

With these preliminary remarks regarding shifts of load on or in the earth's crust, and the way in which the balance thereby disturbed is restored and maintained, under the principle of isostasy, we may now turn to the consideration of mountains.

There are many great mountain ranges in the relief of the earth's surface, the general structure of which is fairly well known to geologists. All these appear to have originated by the operation of compressive stresses in the earth's crust in regions of excessive sedimentation. In both the Rocky Mountains and in the Appalachians, for example, the thickness of sedimentary strata is far greater than in the great plains which extend between these two ranges. Not only is this so, but even more remarkable is the fact that almost the entire volume of sedimentary strata involved in the mountain-making movement, ranging up to about eight miles in thickness, is composed for the most part of beds deposited in shallow water. This means, of course, that the bottom of the basin in which the strata were deposited subsided in proportion, roughly, to the accumulation. We must, therefore, picture to ourselves as the condition which prevailed immediately before the onset of the mountain-making movement, a vast trough in the earth's surface occupied by sediments to a maximum thickness of about eight miles in the middle of the trough, and thinning out both ways to as little as perhaps one per cent. of the maximum. Such a trough or locus of excessive sedimentation is often referred to as a geosyncline. But the only places on the face of the earth where such great thickness of sediments could accumulate are the deltas of the large rivers, where, as has already been observed, very thick deposits become possible by the extension of the deltaic embankment out into deep water, and the subsidence of the sea floor under the depositional load. If this be so, then in the history of the earth great deltaic embankments have been the precursors of folded mountain ranges. And the probable reason for this is that a load of about eight miles of sedimentary strata, spread out over a large area, marks a limit beyond which the surface can not be depressed without collapse under the horizontal stress prevailing in the crust. Thus, if a syncline be regarded as the result of compressive stress, the trough in which deltaic deposits accumulate does not really become a geosyncline until its collapse and the inauguration of the mountain-making movement. The formation of the trough and its filling with incompetent strata are but the preparation for the yielding to compression which makes the syncline. That yielding is the beginning of the deformation which converts the sediment-laden trough into a lofty mountain range. But the compression, and the mashing together of the strata in steeper and steeper folds, signifies a concentration of mass in the

locus of the trough. The load on the crust along its length is increased. The lateral compression induces the development of a ridge, or series of ridges at the surface, and a downward protuberance, several times greater in vertical dimension, into the heavier rocks of the crust. For the mountain-making movement proceeds under control of the law of isostasy; and the deformed mass is at all stages in balance with the rest of the earth's crust.[5]

It is now necessary to consider briefly the general normal constitution of the earth's crust in continental and oceanic regions. On the basis of observation of those portions of it at present exposed at the surface, supplemented by seismological studies of the speed of earthquake waves at varying depths, the crust has been regarded as composed of two main layers: an upper one, generally exposed at the surface of the continents, called the *sial*, and a deeper one called the *sima*. Each of these is further subdivided into two parts. The sial comprises an upper "granitic" layer about 12.4 km thick, having a specific gravity of about 2.6, and a lower dioritic layer about 18.6 km thick, having a specific gravity of about 2.8.[6] The total approximate thickness of the sial is thus 31 km, and its mean specific gravity is 2.72. The sima includes a layer of basalt of limited thickness immediately below the sial having a specific gravity of 3.05, and beneath the basalt a layer of dunite of indefinite thickness and specific gravity of 3.3. There is no sial under the open Pacific Ocean, and the bottom of the basalt is there at a depth of 46.4 km below sea level. If we take the mean depth of the Pacific as 5 km, then the thickness of the basalt in that stable region is 41.4 km, and the relative weight of a column, per unit of surface area, extending down d kilometers below sea level into the dunite, is $5 + 41.4 \times 3.05 + 3.3(d - 46.4) = 3.3d - 21.85$.

The conversion of the deltaic depression into a geosyncline by compressive stress involves the underlying rocks of the trough in the same deformation. Thus the folded and crushed mass, which is depressed to support the new range in obedience to the law of isostasy, includes not only the sial but most probably, also, the basalt of the sima.[7] If this be so, then the entire complex mass, comprising both the elevated and the depressed portions, would have a mean specific gravity of about 2.83. Now, if we consider a great mountain range having a mean altitude of, say, 3 km, we may let d be the depth in kilometers below sea level to which its keel is depressed into the dunite. Its relative weight per unit of area then becomes $2.83\ (3 + d)$, and this is the same as the weight of the oceanic column found above for the same depth.

Thus $\quad 2.83\ (3 + d) = 3.3d - 21.85$
Whence $\quad d = 64.5$ km.

That is to say, for the mountain mass 3 km above sea level there is a thickness of 64.5 km of the same deformed mass below sea level; and the depth of its immersion in the dunite is $64.5 - 46.4 = 18.1$ km.

This depression brings the relatively light crushed rocks into a zone of high temperature, where they are melted into a magma. The mass of the rock thus fused does not change, but its volume increases; and the expansive stress thus created tends to burst the walls of the chamber in which the magma finds itself. Upwards cracks are formed into which the magma flows till equilibrium of pressure is again established. The isostatic equilibrium of the column as a whole is

[5] For a fuller discussion see "The Isostasy of Large Deltas." *Bull. G. S. A.*, 49: 401–416. 1930.

[6] Andrew C. Lawson, *Bull. G. S. A.*, 43: 364–5. 1932.

[7] Andrew C. Lawson, *Bull. G. S. A.*, 45: 1065 *et. seq.*, 1934.

not disturbed, since it neither loses nor gains mass. The magma eventually becomes, by freezing, the granite, monzonite and quartz-diorite so characteristic of the central part of great mountain ranges the world over. And the magma which escapes upward by way of the cracks becomes the material of the satellitic bodies, such as dykes, sills and laccoliths, which invariably accompany the main granitic mass of every great range.

As soon as the new range appears, even as a preliminary ridge, above sea level it passes into the zone of erosion and begins to suffer degradation; the load removed is in part carried away by the rivers to the sea, and in part deposited as alluvial embankments upon its lower flanks. As long as the compressive stress of the earth's crust continues to operate for the upbuilding of the range, its rise may exceed the degradation. But when the compression ceases to operate for uplift, degradation becomes effective for the reduction of its altitude. The erosional removal of load, however, lightens the whole column, and it therefore slowly emerges from the heavy rocks in which its bottom is immersed. The amount of reduction of height is, therefore, not a direct measure of the mean thickness of the layer removed. The lowering of the surface is the thickness of the layer removed by erosion less the rise of the column by levitation. Although the mean specific gravity of the column, is 2.83, that of the sedimentary rocks at the top of it is about 2.67, the usually accepted figure, and for 1 km removed the rise is $\frac{2.67}{3.3} = .8$ km, so that lowering of the surface is $1 - .8 = .2$ km. Or, for a lowering of the surface 1 km the thickness of the layer removed is 5 km. In general, in the early stages of the degradation of the range, the mean thickness of the layer removed is five times the lowering of the surface caused thereby.

As the column, including the large body of molten magma at its bottom, slowly rises, the latter freezes to become the extensive mass of granite rocks we are familiar with in the central part of great ranges. These are exposed to our view by the stripping away of the cover of sedimentary, volcanic and metamorphic rocks, under which they were originally buried.

Although, as we have seen, the rate of lowering of mountain ranges is slow relatively to that of erosional removal, nevertheless they do disappear as major features of the relief of the earth's surface. In the later phases of their degradation, the rate of erosion diminishes steadily, due to the lowering of the grades of the streams and the failure of the lower relief to intercept precipitation from the atmosphere. Eventually the region where the range once stood as a majestic feature of the earth's surface presents no conspicuous relief. It becomes almost a plain at small elevation above sea level, and passes into the category of peneplains, of which there are many. As erosional removal diminishes asymtotically to nothing, the rise of the column, and therefore the rejuvenation of the relief, ceases. The causal mechanism of rise, relief of load, has stopped. The clock has run down, and the region is in static equilibrium.

From the foregoing discussion it appears that the following suppositions are justified as a coherent working hypothesis of the origin of mountains:

(1) Mountain ranges consisting of folded sedimentary strata arise only in regions of excessive deltaic accumulation extending out into deep water.

(2) The depression of the sea floor under the depositional load, and the rise of the surface of the embankment to sea level by depositional accretion permit an accumulation having a thickness of about eight miles.

(3) At this stage the depression of the crust under load begins to collapse due to compressive stress, and a geosyncline is initiated.
(4) The appression of the contents of the trough throws the strata into steep folds, the crests of which are lifted high into the zone of erosion, while the keel of the geosyncline is depressed several times as much into the sima, to secure support by flotation of the uplifted mass.
(5) In the high temperatures of the sima the keel is fused to a granitic magma, which is forced by expansive stress upward and outward, to make dykes, sills and other apophyses in the walls of the magma chamber.
(6) As erosion reduces the new mountain range the whole geosyncline, with its contained magma, rises by relief of load; and the magma eventually freezes to become a granitic batholith.
(7) The uplift is less than the mean thickness of the layer removed by erosion, so that ultimately the range may be, and normally is, reduced to a peneplain.

By way of concrete application of these general considerations we may review the geological history of the Sierra Nevada. The region where that range now stands was until late Jurassic time a portion of an extensive sea in which a great thickness of sedimentary and volcanic rocks had accumulated. In the fullness of time the depression, caused by this load of shallow water deposits, had so weakened the earth's crust that it collapsed under horizontal compressive stress, and the upbuilding of the range was initiated. As the result of a protracted process of deformation the strata were folded and the folds were closely appressed in nearly vertical attitudes. In the uppermost of these strata are fossils of marine organisms of late Jurassic age. Included in the deformation were the much older formations which entered into the makeup of the earth's crust beneath the floor of the Mesozoic sea and probably also the basaltic layer of the sima. The pressure was sufficient to shear large portions of the rocks affected and to induce in them the characteristics of dynamic metamorphism. A lofty range was the result, and this constituted a concentration of mass or a local addition of load upon the earth's crust. It is probable that this range was supported, as more modern mountain ranges are to-day, by the downward protrusion of the lower part of the deformed mass into the heavier rocks of the sima. The mountain range thus brought into being was much more extensive than the Sierra Nevada of today. After the uplift of the range and after the close appression of its folded strata and their dynamic metamorphism, the region of uplift was invaded by a granitic magma from below. The melt made its way upward partly by stoping, partly by fusion, partly by injection and partly by pushing aside the walls of its enclosing chamber. The effect of the melt on these walls was to impose a thermal metamorphism upon the already dynamically metamorphosed rocks. Without resort to pure agnosticism there is little escape from the conclusion that this magma resulted from the fusion of the bottom part of the column depressed into the hot region of the deeper sima. At a later stage the magma rose to higher levels in the crust with the emergence of the column induced by relief of load under erosion. There it crystallized into the granitic rocks so widely exposed throughout the Sierra Nevada to-day. The erosional process, which stripped the granite of its roof of metamorphic rocks, has left many remnants of that roof embedded in or resting on the granite. The embedded remnants have for the most part the vertical attitude of roof pendants, plunging into the granite. These are well exemplified in the vicinity of Mineral King. Others lie in flat attitudes upon the top of the granite, as on Mt. Dana, and on the crest to the west of Carson City. These indicate that the mean exposed surface of the batholith

is but little below the present position of its original top.

When erosion had thus stripped away most of the roof of the batholith, and had exposed its extent very much as it is to-day, the general surface had been so lowered that the summit of Mt. Whitney was only 4,000 feet above sea level. Since then the Sierra Nevada has been uplifted to its present position through 10,500 feet. This rise of the range comprised three distinct movements. The first is measured by the difference of altitude of the two terraces, the Subsummit Plateau and the Chagoopa Plateau, which is .91 km. The second and third movements together are measured by the difference of altitude of the Chagoopa Plateau and the local base level of erosion at which it was formed, and this amounts to 2.29 km. Of this rise only .33 km, the second movement, can be accounted for by erosional levitation. The balance 2.29–.33 = 1.96 km, recognized as the third movement, remains to be accounted for. The only way of doing this is to invoke the operation of the same compressive stress that gave rise to the range in the first instance. In that case crustal compression was applied to a great thickness of incompetent strata sunk in a broad trough, and they yielded by folding and mashing together to form the initial range. In the case we now have to deal with the same compressive stress was applied to a massive buttress of granite which could not fold, but could yield only by breaking and shearing. So the granite broke, and was sheared in such a way as to lift the range 1.96 km higher than it was before the break occurred. This means that the lower part of the granite mass was thrust westward under the upper part on an inclined shear plane; producing an effect as if the upper part had been thrust eastward over the lower.

One direct result of this thrusting was to thicken the granite throughout the extent of the range, and so greatly increase the load on the earth's crust. The additional load could be supported without very notable disturbance of isostatic balance only by the downward protrusion of the thickened batholith into the heavier rocks of the sima. Not only was the load supported, but the surface was raised by flotation 1.96 km. Part of the thickening was taken up in this elevation, but the greater part in the downward protrusion into the sima. The amount of the thickening appears from the following considerations: The mean altitude of the summit region of the Sierra Nevada to-day is about 3.08 km. Before thrusting set in its mean altitude was 3.08–1.96 = 1.12 km. To float a batholith of specific gravity 2.83 to this height above sea level it must have had a thickness of 54.35 km and have been immersed in the dunite 6.83 km. To float the thickened batholith to its present mean height of 3.08 km. it must have a thickness of 68.11 km and be immersed in the dunite 18.63 km. The difference between the two thicknesses, 68.11–54.35 = 13.76 km, is the measure of the thickening by the thrust movement.

The conclusion thus arrived at, that the Sierra Nevada as we know it to-day, owes its last important uplift of 1.96 km to a thrust, which thickened the batholith and caused it to float higher, necessitates a revision of our notions of the fundamental structure of the range. The current conception among geologists is that the eastern front of the range is the degraded scarp of a zone of normal faulting. It is supposed that after the region had been reduced by erosion to comparatively low altitude and subdued relief, it was dislocated from the country to the east and tilted up on a normal fault, dipping eastward, the face of which now overlooks the deserts of Nevada. A reciprocal down-

ward drop to the east of the fault is of course not excluded from this hypothesis. But this notion fails to supply any mechanism for the uplift of the mountain block. Thrusts are common features in the crust of the earth, some of them of great magnitude. They always necessarily thicken the crust; and if the region affected be large enough, so that the rigidity of the crust is inadequate to support the increase of load, the thickening causes the crust to float higher, so as to preserve isostatic balance. There are numerous normal faults along the eastern front of the Sierra Nevada, but that front is not fundamentally the scarp of a normal fault. It is the edge of a thrust block, and the underlying thrust plane, on which the block rides, is due to emerge in the bottom of the alluvium-filled valleys at the foot of the steep eastern slope. The normal faults are secondary features, significant of minor gravitative adjustments, necessitated by the thrust movement. It would be difficult to visualize the locus of emergence of a great thrust free from secondary normal faults.

It is perhaps worth noting in conclusion that, if the thrust plane on its downward dip under the region of the Great Valley, intersected and thickened the heavy rocks of the sima, the column embracing the thickening of that portion of the crust would be abnormally heavy and would sink. If the incorporation of the excess heavy rock into the general body of the sima be a slow process, the initial uplift of the surface might be removed by erosion before it was accomplished; and, when the subsidence of the column was finally effected, there might be a depression of the surface above the zone of original thickening, a structural valley, which would become a trap for sediments and so have the general characteristics of the Great Valley of California.

THE HORMONES AND VITAMINS OF PLANT GROWTH

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THE phenomenon of plant growth has a very intimate bearing upon many of the activities of mankind. In fact, the very existence of man, and of animal life in general, depends in the last analysis upon the vegetation of the world. Plant growth has, therefore, been the subject of study by man for many centuries. The investigations of the past have dealt primarily with the effects of various external factors on plant growth and development, and the influence of such factors as light intensity, temperature, fertilizer, etc., has been studied. For each plant there is an optimum combination of these external factors. Given this optimum combination, there are, however, still other factors and in particular ones inside the plant, which limit its growth. We say that the growth of the plant under these optimum external conditions is limited by "internal factors."

A knowledge of these "internal factors," what they may be and how they operate, is of course necessary before we can hope to control plant growth according to our desires. It is only during the past ten years that significant advances in the understanding of this problem have been made. We now know that some of these internal factors are special chemical substances that are present in the plant and which regulate its growth just as the special chemical substances of the pituitary gland regulate the growth of the human being. In this article we shall survey some of the experimental methods and review some of the results of the work on the hormones of plants. Much of the work has been done by the plant physiology group at the California Institute of Technology although the work of other institutions will also be discussed.

It would be well to make clear at once what is meant by the terms "hormone" and "vitamin." Almost 60 years ago, Julius Sachs, the father of modern plant physiology, came to the conclusion, based upon theoretical considerations, that effects of one part of the plant upon other parts, the "correlations" within the plant, must be ascribed to individual chemical substances. These substances, Sachs reasoned, must be present in very minute amounts, but must have effects out of all proportion to their relatively low concentrations. Sachs also clearly differentiated these substances from the ordinary "foods" which are substances present in relatively large amounts, and out of which the bulk of the plant may be built. Some 25 years later it became clear that specific chemical substances function also in animals as "chemical messengers," connecting the activities of one organ with those of other organs. To such substances Starling in 1904 gave the name of *hormone*. A hormone is then essentially a substance which is produced in one part of an organism, is transferred to another part, and there, in very minute amounts, influences a specific physiological process. A hormone is, as its name implies, a chemical messenger, which "tells" other parts of the organism how they must respond.

The vitamins, on the other hand, are specific chemical substances which are needed by the animal body, but which the animal body is unable to make. Animals are fortunately able to obtain these necessary substances from plants, many

of which are able to synthesize vitamins as by-products of their photosynthesis. A vitamin, like a hormone, is needed in the body for specific physiological processes. A hormone, however, is produced in particular organs of the body itself. A vitamin, on the other hand, must be supplied from the outside; must be supplied with the food.

The distinction between a hormone and a vitamin is not by any means sharp. A substance which is a hormone for one organism may be a vitamin for other organisms. Thus ascorbic acid (vitamin C) is not formed by most higher animals and must be supplied to them. The rat, however, is able to produce ascorbic acid in its own liver, and this substance is then really a hormone for the rat.

The striking manifestations of plant growth, such as the spectacular growth of a seedling or the unfolding of a bud, are due to an increase in size of cells. The increase in size of plant cells is controlled by a number of internal factors but chief among these is a specific chemical substance, a hormone, known now as auxin. Let us consider a few of the experiments which show how auxin is formed in the plant and see how it influences growth.

When an oat seedling grows, its leaves are surrounded by a hollow sheath known as the coleoptile. The coleoptile elongates from a length of one or two mm. to almost four cm, during which time only a few cell divisions take place. Its growth is almost purely by cell elongation. It is therefore a suitable and convenient object for the study of cell extension, and has been used a great deal in the study of auxin. The oat coleoptile does not grow at the extreme tip and it does not grow at the extreme base. It grows rather by elongation of a zone near its middle. If the tip of the oat coleoptile is removed, that is, if the coleoptile is "decapitated," the growth rate of the remaining portion quickly drops to a low value. If, however, the tip is replaced on the "stump" immediately after it has been removed, the growth rate of the coleoptile is not greatly retarded. The tip exerts an influence on the growth of the lower portions of the coleoptile, and this effect can be transmitted across a cut surface. It may even be transmitted across a thin sheet of gelatin inserted between tip and coleoptile stump. If the coleoptile tip is removed and then placed on one side only of the coleoptile stump, the growth effect is transmitted only down one side. This side grows more than does the other, and as a consequence, the coleoptile bends. The demonstration that the effect of the coleoptile tip on growth is due to a growth hormone is, however, due to a classical experiment of Prof. F. W. Went in 1927. A coleoptile tip is removed from a plant and placed on a small block of agar for a time. The tip is then removed from the agar, and the agar applied to the stump of a decapitated coleoptile. These agar blocks are able to bring about growth just as were the original tips themselves! The effect of the tip may be made to pass into agar, and from the agar back into the plant. From this experiment it is a safe inference that the growth effect is due to some chemical substance.

A simple and quantitative method of determining the "growth substance" may be had by the application of an agar block, containing the growth substance, to one side of a decapitated coleoptile. The coleoptile grows more on the side with the agar block than on the other side, and the resulting curvature is proportional to the amount of growth substance in the agar block. If rigidly standardized conditions are adhered to, this method may be used for the quantitative determination of the growth substance. It is in fact possible to use this test so effectively that concentrations of growth substance may be determined to within 5 per cent.

We now know that only very small

amounts indeed of this chemical growth substance are present in coleoptile tips. If 20 people were to do nothing but cut the tips from seedlings, so that these tips could be used for the isolation of the substance, these 20 people would have to cut steadily for about 125 years to obtain 1 gram of the hormone. Interestingly enough, however, there are relatively large amounts of the substance present in human urine, and two organic chemists in Holland, Prof. Fritz Kögl and Prof. A. Haagen-Smit, began several years ago to isolate it. At every step in the fractionation procedure they used the oat-bending test to determine quantitatively into which fraction the "activity" had gone. In this way they were able, after they had concentrated the material approximately 100,000 times to isolate a crystalline substance of which approximately 2×10^{-11} grams sufficed to give a 10 degree curvature of an oat coleoptile. Kögl and Haagen-Smit have isolated less than one gram of this crystalline substance, yet even with this small amount they were able to work out its chemical structure. Kögl gave this substance the name *auxin*, or more particularly auxin-a, since there is a closely related substance differing by the elements of one molecule of water which is called auxin-b.

Shortly after the isolation of auxin-a, the isolation of still another active substance was announced. This substance also possesses great activity in the oat test, *i.e.*, is capable of causing bending of the oat coleoptile in amounts about twice as great as those of auxin-a which are needed. This substance is a well known substance, indole-3-acetic acid. Indole acetic acid apparently possesses all of the effects upon plants which auxin-a possesses, but it does not occur naturally in higher plants. It is formed rather by bacteria and molds as a by-product of their metabolism. Indole acetic acid is now, however, readily available since it can be easily synthesized in the chemical laboratory. This discovery of indole acetic acid has opened to the physiologist the possibility of experimenting directly with one of the internal factors of plant development.

The work discussed thus far has dealt only with the oat seedling. However, it is necessary to stress again that auxin regulates cell elongation in other organs and in other plants. In all of the higher plants thus far carefully examined, in the growth of veins of leaves, of petioles, of flower stalks, of stems in general, auxin is present and regulates growth just as it does in the oat coleoptile. Auxin even influences the growth of such simple plants as the uni-cellular algae.

The way in which auxin acts on plant cells to bring about this general increase in size is not yet completely understood. It is known, however, that one end result of the action of auxin is increase of the extensibility of the cell wall which covers the surface of every plant cell. The plant cell in many ways resembles a balloon which is blown up with water pressure rather than with pressure of a gas. Auxin makes the balloon more extensible so that it can expand more rapidly.

We might next examine a few of the other plant growth phenomena that are regulated by auxin. The phototropic and geotropic movements of plants, that is, the movements by which plants assume favorable positions with respect to light and to gravity, are all growth responses. If light falls on one side of a plant this illuminated side grows slower than does the non-illuminated side and the plant as a result bends toward the light. This is almost wholly due to the redistribution of auxin within the plant as is shown by the following experiment. A small cylindrical piece of stem is taken, and at the top is placed an agar block containing auxin. At the bottom are placed two blocks which do not contain auxin and which are separated by a razor blade. Such an arrangement is allowed to stand

for one hour. The bottom blocks are then removed and placed upon oat seedlings, and their auxin contents determined by the curvatures which are produced. If the original experiment was carried out in darkness, the two bottom blocks are found to contain equal amounts of auxin, just as would be expected. If, however, light is allowed to fall upon one side of the stem section during the experiment, it is found that the block under the illuminated side contains less auxin than that under the non-illuminated side. Under the influence of the one-sided light, then, auxin, during its downward transport, has moved from the light side to the dark side. This also happens in the normal plant. As a consequence the non-illuminated side, with its greater amount of auxin, grows faster, and the plant curves toward the light. The response of plants to the force of gravity is quite similar in principle. When a plant is placed in a horizontal position auxin moves from the upper to the lower side of the stem. As a consequence the lower side grows faster than does the upper side and the plant curves upward to regain its normal vertical position.

Dwarf growth habit in plants is sometimes also an auxin phenomenon. In corn, for example, there are a number of dwarf races known, each one of which depends upon a single recessive genetic character. The case of one of these dwarfs, known to corn geneticists as "nana," has been studied in detail. Nana plants differ from the normal in that the stems are very short. The leaves, however, are approximately normal. As the result of the short stems, the leaves appear to be crowded in a rosette. It is now clear that these dwarf corn plants are dwarf because they lack sufficient available auxin. Although nana plants produce almost as much auxin as is produced by normal plants, the activity of oxidizing enzymes in nana plants is much greater than that in the normal, and as a result the nana plant destroys, oxidizes, its own auxin very rapidly, so that in such plants very little auxin reaches the rapidly growing portion of the stem. If nana plants are properly treated artificially with large amounts of auxin they are able to grow quite as well as are normal plants. In this case, also, we are able to say a little about the manner in which a genetic factor, a "gene," exerts its effect. The gene "nana" causes an increased oxidizing enzyme activity, this in turn causes an increased destruction of auxin, this leads to auxin deficiency in the plant, and the plant is then dwarf.

Plants which grow at high elevations, for example in mountainous regions, are known to be in many cases of smaller stature than related plants growing at lower elevations. There are probably many influences which contribute to this "high altitude dwarf growth," but one of these factors, also, is related to auxin. Auxin is destroyed by ultra-violet light and it seems probable that plants grown in high regions with the attending higher intensity of ultra-violet light, suffer from auxin deficiency, just as do plants experimentally irradiated with ultra-violet. Some of the dwarf plants of mountain tops may then be "auxin deficiency dwarfs" just as are corn plants which carry the genetic characters for dwarf growth.

One other function of auxin in the plant might be mentioned here, namely, its rôle in bud inhibition. From early times it has been known that the lateral buds (the buds at the base of each leaf) usually do not develop in the presence of a terminal bud. If, however, the terminal bud is removed, as for example when a shrub or tree is pruned, some of the lateral buds grow out at once. We say then that a terminal bud "inhibits" the lateral buds. This problem was attacked by Prof. K. V. Thimann and Dr.

F. Skoog. They showed that the terminal bud is the most active auxin producing center in the plants with which they worked, that is, in peas and beans, and that the dormant lateral buds produce almost no auxin. If, however, the terminal bud is removed, the lateral buds immediately commence to produce auxin and consequently to grow. Agar blocks containing auxin were then applied to plants whose terminal bud had been removed. The artificially applied auxin inhibited the growth of the lateral buds quite as well as did the normal terminal bud, and they therefore justifiably concluded that it is the auxin secreted by the terminal bud which causes inhibition of the lateral buds. This mechanism of bud inhibition has been shown to hold for many different kinds of plants and is apparently quite general. It is also of interest that many dwarf races such as those of peas and beans, etc., tend to have a bushy habit, that is, that they tend to have extensive development of their lower lateral buds. This is quite possibly due to the same cause as the dwarfing itself, namely to the low auxin concentrations present in the dwarf plant. Not only is there not enough auxin present to suffice for normal growth; there is also not enough auxin present to cause normal bud inhibition.

Only the growth of stems and of buds have been considered thus far. It is now time to turn attention to that retiring but important part of the plant, the root. Auxin does not in general stimulate root growth, and in fact the concentrations of auxin which stimulate the growth of stems are very inhibitory to the growth of roots. There must be then other hormones which are necessary for the growth of roots, and a program for the elucidation of these hormones was embarked upon. Hormones which affect the growth of the root should come either from the upper parts of the plant or from the soil. In order to study these root growth hormones the root should be isolated from these two sources of supply. It is then possible to determine what substances we must "feed" the root in order to make it grow. A short root tip of a pea seedling is cut from the plant. This root tip may be grown in a glass vessel as an isolated root if the proper nutrient solution is supplied. By a long series of experiments a nutrient solution was determined which would permit isolated root tips to grow 1 cm or more per day, that is, to grow even faster than they do when they are attached to the normal plant. This nutrient solution contained only the ordinary "food" substances such as salts and sugar. A second short tip may be cut from such an isolated root that has grown for several days. This "second generation" root tip grows but very little if it is placed in nutrient solution. If still a third time a tip be cut from the root and placed in fresh nutrient medium, it does not grow at all. The original root tip must have contained some substance which is needed for the growth of roots and which is gradually used up so that the isolated root is not able to grow indefinitely in this solution containing only ordinary foods. The problem now was to find out what this substance might be.

If a very small amount of yeast extract, 0.01 per cent. or less of water extract of yeast is added to the medium in which isolated roots are grown, the roots are able to grow for many months at a rate of 1 cm or more per day. Fresh tips may be cut from these roots weekly and placed in fresh nutrient solution, but if the solution contains this small amount of yeast extract in addition to the ordinary foods, the roots grow almost as well as do normal roots which are attached to the plant. There is then something in yeast extract which is essential for the continued growth of the root, and experiments were made to determine the chemical nature of this something.

Fortunately it soon became clear that the substance was associated with the vitamin B complex of yeast, and tests were made with crystalline preparations. The root growth factor was found to be identical with vitamin B_1, the anti-neuritic or anti-beri-beri vitamin, a substance whose chemical structure and synthesis had been finally worked out a few months before by Prof. R. R. Williams, and which is a rather peculiar substance containing the heterocyclic thiazole ring, not before known to occur in nature.

It is appropriate to note here the peculiar status of the vitamins as far as plants are concerned. At the end of the 19th century Eijkman first showed that the anti-neuritic vitamin occurs in large amounts in seeds, and there has since been abundant data collected as to the universal occurrence and distribution of the several vitamins in plant material, in seeds, leaves, stems, roots, and even flowers. However, it seems to have been tacitly, although very generally, assumed, that the plant produces these substances as a sort of a friendly gesture toward the animal world, that vitamin B_1 was produced by plants so that animals would not get beri-beri. This assumption was of course false, and as we shall see, the vitamins, not only vitamin B_1 but the other vitamins as well, are produced by plants because they play important rôles in plant development, and they are stored in seeds because they are needed for the growth of the seedling plant.

Now that we know that vitamin B_1 is necessary for the growth of roots, it is possible to understand why the tips which are freshly cut from the seedling plants are able to grow even in nutrient solution which does not contain the vitamin. Root tips freshly cut from the plant contain quite large amounts of vitamin B_1, and hence are able to grow well even if more is not added to them. Tips taken from the isolated roots after they have grown contain, however, much less vitamin B_1 and are limited in their growth by this substance. Tips from these "second generation" roots contain no detectable amount of vitamin B_1. These tips if they are examined with the microscope give a very interesting clue as to the way in which vitamin B_1 affects root growth. In these vitamin B_1-free roots there are few if any cell divisions. The cells which are present elongate, mature, deposit starch, and differentiate into the various root tissues in an approximately normal fashion. These processes then do not depend greatly on vitamin B_1. The cell divisions of the root tip, however, depend upon the presence of the vitamin. Whereas auxin, the stem growth hormone, influenced cell elongation, vitamin B_1, the root growth factor, influences cell division.

The amounts of vitamin B_1 which are needed by the root are very minute. The normal pea root tip contains only about one ten-millionth of a gram of the vitamin. The amounts of vitamin B_1 which just cause a detectable effect upon root growth are still less than this. For example, a solution which contains 1×10^{-11} grams of vitamin B_1 per liter still causes a measurable effect upon root growth. One gram of vitamin B_1 would suffice for the growth of a root at least 1200 miles long!

Vitamin B_1 is not only a growth factor for pea roots. On the contrary, it is a very general growth factor for roots. Of the many plants thus far examined not one has failed to respond to this substance with increased growth of roots.

In the normal plant vitamin B_1 is formed in the green leaves. From the leaves it is transported to the roots where it exerts its effects upon root growth. In the normal green plant vitamin B_1 is therefore a plant hormone just as is auxin. It is a substance which is produced in one place and is transported to

another where it exerts its effect. The isolated root, however, can not obtain its vitamin B_1 supply in this way and this substance must therefore be supplied in the nutrient solution with which the root is fed. Vitamin B_1 is a *vitamin* for the isolated root.

Up to this point we have considered what may seem very academic aspects of the internal factors controlling plant development. Let us now consider some of the practical ways in which this knowledge can be applied. One of the ways is in that classical horticultural problem, the rooting of cuttings. The rooting of cuttings has always been a very empirical procedure. Cuttings of some plants root spontaneously when the base of the cutting is placed in moist sand. It has never been possible to root the cuttings of many other plants. Several years ago an investigation of the internal factors involved in the production of roots on cuttings was taken up. It was found that there is something produced in leaves and in buds which is able to cause the initiation of "root primordia," that is, of embryonic roots, at the base of the cutting. On some cuttings these embryonic roots grow out into visible roots, and we say that the cutting has "rooted." It was also found that there is a something, different from the first, which is necessary for the growing out of these embryonic roots. This second substance comes from the leaves. The chemical nature of the substance which is needed for the initiation of roots was next investigated. To the great surprise of everyone, this substance soon turned out to be identical with auxin! The effect of auxin on initiation of roots is of quite a different nature from its effect on cell elongation, and to discuss the reasons for it would lead us too far afield. However, the fact is that auxin, through its interaction with still other internal factors, is able to cause the initiation of embryonic roots on cuttings of a great many different kinds of plants. This fact has been made use of in horticultural practice upon wide scale, and auxin is now sold to the public for this purpose under a variety of trade names.

Auxin treatment, as has been explained already, affects the initiation of embryonic roots. What the horticulturist desires, however, is well-developed, well-grown roots. With many cuttings auxin causes the initiation of embryonic roots, but these fail to develop further. Even with favorable plants only a fraction of the root primordia which are initiated actually grow out. It has also been observed that cuttings taken at what are called "unfavorable" times of the year, for example immediately after very cold weather, fail to develop many visible roots after auxin treatment. Embryonic roots are formed by the auxin treatment but these fail completely to develop further. All of these facts point to the need of treating cuttings with a root growth factor. When vitamin B_1 was found to be such a root growth factor, it was immediately used to aid in the rooting of cuttings.

Experiments were made in which cuttings of plants which are notoriously difficult to root such as some of the Camellias, were treated at the base with auxin in the usual way. Embryonic roots developed on these cuttings after several days. Then the cuttings were treated with vitamin B_1. Within 24 hours the embryonic roots began to grow out, and in a few days the cuttings had many long roots. The results of this "double treatment" are often spectacular. Healthy, well-rooted cuttings can be obtained within two to four weeks, of many plants which it has not been possible to profitably propagate from cuttings before.

With plants whose cuttings normally produce some visible roots after auxin treatment, the rooting can often be improved by application of vitamin B_1. A

good example of this type is the lemon cutting. In fact, no plant which has thus far been investigated has failed to at least improve the rooting of its cuttings with vitamin B_1 treatment, indicating again that this substance is a very general factor for root growth.

It is of interest to note that the differences in the rooting of cuttings, taken at what gardeners call "favorable" and "unfavorable" times of year, tend to disappear when cuttings are rooted with this combination of factors for root initiation and root growth. Thus even leafless hardwood cuttings can be successfully rooted, with plants which otherwise would not root at all. It seems probable that the differences in the ease with which cuttings root spontaneously at different times of year are due in the first place to seasonal differences in the amounts of auxin and vitamin B_1 present in the cuttings when they are cut from the plant.

The rooting of cuttings has now been put on a rather exact basis as a result of these investigations of the internal growth factors which are involved. There are other ways in which plant growth can be controlled by the use of these factors, but only one need be mentioned here. In the past few years there has been much interest in the growing of plants under carefully controlled conditions, with their root systems either in a mineral nutrient solution, or in washed sand watered with nutrient solution. Plants grown under such conditions of "tank culture," "hydroponics," or of sand culture, develop under optimal or near optimal external conditions and may give very large yields. Their growth under these optimal external conditions is, however, limited by internal factors, and for any further improvement in their growth an attempt must be made to find what internal factor is limiting. Recent experiments have shown, in fact, that some plants in tank or sand cultures may be accelerated in their development by the application of vitamin B_1 to their culture solution. These plants apparently do not produce in their leaves as much vitamin B_1 as the roots can use. Accordingly, the root system is limited in its development by this internal factor, and shoot development is limited by root development, as we shall shortly see in another connection. Application of vitamin B_1 should allow the roots to grow more vigorously and accordingly shoot growth to be also improved. Needless to say, it is not expected that all plants are limited by vitamin B_1; different plants are undoubtedly limited by different internal factors, but it seems reasonable to suppose that it is along this line that further improvement of tank culture crops must proceed.

The internal growth factors which have been most extensively studied and which are at present best understood are auxin and vitamin B_1. There are, however, many other factors of this type. There is, for example, the substance given off by injured cells which is responsible for the healing of wounds as well as for abnormal growths of various kinds. The chemical nature of this substance has been investigated but its chemical structure has not yet been worked out in detail. Perhaps the most general and most interesting test for plant growth factors is, however, the "isolated embryo" test. In this test, the embryo is removed from the seed so that it is unable to obtain either the food or the growth factors which are stored there. The aseptic embryo is then placed in a sterile flask containing nutrient solution. This solution contains sugar from which the plant is able to derive the energy necessary for its metabolism, and in addition the solution contains all of the necessary mineral salts. The embryo is allowed to develop in this medium in the dark. The embryo, under these conditions, is completely dependent on the

medium both for food and for special growth factors. The ordinary foods, however, are all supplied in the nutrient solution in amounts sufficiently large to be non-limiting. The growth of the embryo is then limited only by the special growth factors in the medium. As one can readily see, this is a very general and delicate test for the substances necessary for plant development. Very extensive experiments of this kind have been carried out with the isolated embryo of the pea. If no special growth factors are added to the nutrient solution, the embryo grows into a dwarf plant approximately 1.5 cm high. That it is able to grow at all is due to the fact that the embryo when it is cut from the seed already contains a certain amount of each specific growth factor. In order to make this plant grow more, we must now try to give to it, in the nutrient solution, the growth factors which it normally gets from the seed. If vitamin B_1 is supplied, the root growth of the young plant is very considerably improved. The amount of vitamin B_1 which is necessary to bring about this effect is of the same order of magnitude as that normally present in the pea seed. At the same time, the stem growth of the plant is greatly improved. Vitamin B_1, however, has no detectable influence upon the growth of isolated stems, and it seems reasonable to conclude that its effect upon the growth of the stem must be indirect and due to its effect upon the growth of the roots. The roots grow much better when vitamin B_1 is supplied and as an indirect result of this the stem also grows better. Vitamin C, ascorbic acid, also, is a growth factor for these isolated embryos. Vitamin C must be absorbed by the embryo until it reaches approximately the concentration which is present in the normal plant in order for it to exert its maximum effect in increasing the growth of the isolated embryo. Finally, pantothenic acid exerts an influence upon these embryos. Pantothenic acid is one of the group of "bios" factors that is necessary for the growth of yeast, but it also is present in the pea cotyledon and appears to function in some rather direct manner on the growth of the seedling shoot. Still others of the known "biologically active" substances influence the growth of excised pea embryos. Vitamin B_2 and nicotinic acid, two other substances of the vitamin B complex, have such effects and are undoubtedly to be regarded as plant hormones although their specific functions have not as yet been worked out. Theelin, one of the female sex hormones of animals, should also be mentioned in this connection. It has been known for some time that substances having oestrogenic activity are present in plant material, in leaves and in seeds, for example. In fact, when this was first discovered it was suggested that the oestrogenic substances might function in some way in regulating the reproductive processes of plants. This undoubtedly is not so, for it is in general not possible to bring a plant into flower by applying oestrogenic substances to it. However, there is abundant evidence that theelin is able to improve the vegetative growth of plants under some conditions. It is stored in seeds, and consequently one might well suspect it of being necessary for the growth of seedlings. In fact, it is quite potent in improving the growth of the plant in the isolated embryo test. If several of these individual growth factors are combined, the embryos grow somewhat better than they do with only one of the growth factors. However, there must be still other, as yet unrecognized factors, involved, for we are not yet able to duplicate *in vitro* the growth of a normal pea seedling. It seems safe to prophesy, however, that as we seek for these other growth factors, using this test which appears to be so far

removed from practical problems, we may nevertheless learn still a great deal more about the ways in which plant growth may be controlled under practical conditions.

One example of what might be done with even a small knowledge of the bud growth factors may be mentioned. The peach tree, like many other deciduous trees, requires a certain amount of winter "cold treatment" if it is to resume its normal growth the following spring. In warm climates such as that of Southern California the winters are often not sufficiently cold to furnish a satisfactory cold treatment, and as a result the buds of peach and of some other trees fail to open at the normal time in the spring. This is known as "delayed foliation" and may often be so extreme as to cause considerable losses. This is a problem in failure of buds to grow. It is not a problem concerned with the usual foods because chemical analysis has shown that there are large amounts of food present in the dormant twigs. It might be supposed that it is a problem related to the specific growth factors, and this seems indeed to be the case. Dormant buds can in some cases be caused to resume their growth if they are supplied with those growth factors which, as we saw earlier, affect the growth of the isolated embryo. It may perhaps be predicted that through a knowledge of these internal growth factors dormancy may be completely controlled.

In this article a few of the results of the investigation dealing with the internal factors involved in plant development have been discussed. To sum up: The growth of stems can be regulated to a considerable degree with the aid of auxin. Internal factors other than auxin play a rôle here, however, and one cannot yet say that stem growth is completely under our control. Root growth, on the other hand, is relatively well understood. Not only root growth itself but the formation of roots can be regulated rather exactly. This, however, is as far as the study of the internal factors in plant development has progressed. The general line of attack which it is necessary to make upon this type of problem is, however, clearly understood and progress in the future will be much faster. There are many problems, problems outstanding both because of their practical and their theoretical interest which can now profitably be attacked; for example, that of the initiation of buds, of growth in thickness, of leaf growth, and of fruit development. In all of these cases it seems well indicated that special substances, hormones, or more generally, special growth factors, are involved, and that much might be elucidated by an appropriate "hormone attack." The problem of dormancy also gives promise, as has just been indicated, of being a problem involving special internal growth factors. Flower bud initiation and the growth of flowers are practical problems of the first importance which are yet to be studied from this point of view. The study of the plant hormones is admittedly still in its infancy, but it is a study which holds bright promises for the future.

SCIENCE AND SOCIAL VALUES

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THE distinguished pharmacologist, John J. Abel, has stated his ideal in a sentence: "Greater even than the greatest discovery is to keep open the way to future discoveries." In other words, nothing should be allowed to stand in the way of scientific advance. Personally, I would rather alter this statement to read: Greater even than the greatest discovery is to make proper use of discovery. This is not very different from the instructions of Saint Paul: "Prove all things; hold fast to that which is right." Thoughtful people are apprehensive about the misuse of Science.

According to Raymond B. Fosdick, president of the Rockefeller Foundation: "Humanity stands to-day in a position of unique peril. An unanswered question is written across the future: Is man to be master of the civilization he has created, or is he to be the victim? Can he control the forces which he has himself let loose?"[1]

And the Nobel prize winner, Alexis Carrel, has written: "The enormous advance gained by the sciences of inanimate matter over those of living things is one of the greatest catastrophes ever suffered by humanity. The environment born of our intelligence and our inventions is adjusted neither to our stature nor to our shape. We are unhappy. We degenerate morally and mentally."[2]

Dean G. S. Ford, at the moment acting president of the University of Minnesota, has approached the problem as an educator. He is concerned with the kind of science which is fed to the people of the United States. He says: "Nobody today needs to have his intellectual gullet enlarged so that he can swallow more unbelievable marvels of science. We do that now without batting an eye. What keeps us socially and individually retching and in distress is the string tied to science and the things it drags along with it . . . our gorge rises now, meaning our prejudices, intolerances, accustomed and inherited ways of thinking and acting, so that there are people who would have society stick its finger down its throat and get rid of science, at least temporarily."[3]

Harold G. Moulton, president of the Brookings Institution, tells us very concisely for what science is blamed: ". . . for developing an industrial organization of such vast complexity as to baffle human control; for creating an international economic structure in a world of political nationalism; for building implements of warfare which threaten the very extinction of peoples; for so mechanizing work processes, as to dull the qualities of human intelligence; for changing the relative rates of population growth in the upper and lower strata of society; for bringing into existence new forms of goods and services in such rapid succession, and in such profusion as to make it difficult for slowly changing human beings to assimilate them; for giving us leisure that we do not know how to use; for producing chronic unemployment and the grave social problems which it entails; for building up a capacity for production beyond our powers of consumption; for creating an artificial way of life in place of the old simplicity; and for distorting ethical values and undermining religion and morals."[4]

[1] H. G. Moulton, *Science*, February 25, 1938.
[2] *Ibid.*

[3] B. C. Gruenberg, "Science and the Public Mind." New York: McGraw-Hill Book Company, 1935, 196 pp.
[4] H. G. Moulton, *loc. cit.*

This arraingnment of science is breath-taking. But we all know that science is a kind of two-edged tool which can cut both ways. An immense amount has been said and written about the use and misuse of science. Obviously, in the short time at our disposal, we can but scratch the surface. No two people would do so in the same way. We shall limit ourselves to five ways in which our social body politic feels the impact of science.

(1) It is natural to think first of *unemployment*. Even the most learned understand this but imperfectly. Men and women in many occupations are being displaced by machines. This is happening, for instance, as a consequence of the installation of labor-saving machinery in steel rolling mills. Since 15 men are thus enabled to do more than 1,200, it is estimated than 85,000 will be permanently displaced within three years.[5]

Each great labor-saving device may be a step forward in social values, but we would rather have it without this social dislocation in its wake. It is said that the maladjustment is corrected by the development of other new industries which absorb the unemployment. While this statement may have some basis in fact and be a sort of half-truth, it carries with it a lot of wishful thinking. There is a parrot-like quality in its insistent repetition—a sort of defense reaction. As science advances, new industries are developed which take up part of the slack, but unemployment on the whole tends to increase. The shock of the utilization of each invention should be considered on its own merits unobscured by doubtful generalizations. When 10,000 men, who have done their duty over many years and have earned a fair living for their families, are deprived of the jobs in which they have become proficient, and this almost without warning, exactly what are they to do? These 10,000 may not happen to be in a locality where a new industry is developing. Even if they are, their training may not be such as to lead to their employment. They and their dependents are likely to experience a terrible jolt which will cause years of suffering. It is almost as bad, when industries move to another part of the country, nearer raw materials or cheaper labor, and leave the original workers behind.

This is of course a matter about which much could be said. There is a limit to which a minority must be protected at the expense of failure to make the fruits of science available to the majority at a price which they are fully able to pay. We shall revert to age and sex factors in unemployment later.

(2) Some assert that advances in science promote *mediocrity*. If any considerable number of laborers are to become mere button pushers, opportunity to cultivate skill and pride in accomplishment will be lost. Manual laborers on relief, numbered by the million, sometimes work in a rather half-hearted fashion, though there are, thank heaven, many exceptions. When the work is of remote, or even of no social value, the effect on them can not be described as uplifting or stimulating. It is given to them because of our belief in the right of all workers to a living wage. Whether they are good, bad or indifferent makes but little difference. We are unwilling to let the fit survive and to see the unfit go under. In labor we see a marked leveling.

And the same tendency is noticeable in education. This, beyond the acknowledged minimum of the three R's, like work, is the right of all whether they earn it or not. The tempo of mass-education is all too frequently adjusted to the dull and the stupid, even to the pathological, with whom the promising youngsters must keep step. Again the premium which used to be placed on

[5] Marquis Childs, *St. Louis Post-Dispatch*, March 6, 1938.

initiative and brains is going by the board. Science, however, is not so much to blame as our conception of relativity in social values.

(3) Mediocrity is partly due to *coddling*, which, from another angle, is definitely a result of advances in science. Thus, we are protected from disease by improvements in medicine; from changes in temperature by proper clothes, heating and, for the chosen few, by air conditioning; from having to use our muscles by all kinds of mechanical devices. We could mention many other ways in which our bodies are pampered while our minds are stimulated to a fever pitch. Our control of external environment is becoming so perfect that there is real danger of loss of God-given powers of adaptation through disuse.

Jennings has aptly said: "All organisms *must* protect themselves against the injurious forces of nature: against heat and cold and wind and wet; against starvation and overeating; against unfit food and drink; against bumps and bruises and broken bones; against plagues and poisons. That's what life is; a struggle for existence. If any organism ceased to struggle, ceased to select its environment, ceased to protect itself —its kind would become extinct in a generation. So it is with man, with bird, with fish, with worm, with protozoon, with plant."[6]

But unlike lower animals, as Darwin and numerous leaders since have told us, we prevent the operation of natural laws. We will not allow mankind to become extinct in a generation, but what the distant future holds for us if we rely more and more on machines and less and less on our bodies we can not tell. Such dependence does not make for progress.

(4) With labor becoming more mechanical, with reduction in hours and increased idleness there is no doubt that susceptibility to *propaganda* increases. This menace to freedom of thought and action is as old as history, but it comes to us with new and almost irresistible impetus.

Plato, in his discussion of tyranny, has given us a clear view of propaganda. "Tyranny is not so much a form of government as political death, or sleep during which all conscious exertion of power is extinguished. The people, like a vast mass of brute matter, are fashioned by their tyrant into whatever form he pleases: he sends jugglers among them, under the name of priests, who fill them with dreams favorable to tyranny; by the instrumentality of these men, he darkens their minds, stupefies them with intellectual mandragora, and gradually plucks up by the root every free and manly and noble sentiment; ultimately, with more than Circean art, he transforms them into hogs, rings their noses, and turns them to grunt, feed and fatten for his use in the sty of slavery."[7]

It is interesting to note that the principles of propaganda and of hypnotism are identical. They are to eliminate all thoughts which give balanced judgment, so that the force of the one remaining is so greatly enhanced that behavior is unconsciously determined thereby. Knowledge of the details of hypnotism, coupled with the onward rush of mechanical science, radio, movies, telegraph, etc., make propaganda a more potent force in shaping human behavior than ever before. In the hands of a dictator it is of all the most socially destructive influence of science. We, in great centers of learning, who enjoy a generous measure of freedom of thought and behavior, should be more resistant than others who are less fortunate. All too frequently we follow like sheep.

(5) The social organism in which unemployment, mediocrity and dependence

[6] H. S. Jennings, "The Biological Basis of Human Nature." New York: W. W. Norton and Company, Inc., 1930, 384 pp.

[7] Quoted from St. John's translation, 1838.

are perhaps on the increase and from which judgment is sapped by propaganda is *aging*. Owing to advances in medical care and to improvement in living conditions most of us last longer than our forefathers did. Life expectancy is the number of years that the average new-born babe will live. It is what insurance companies use in calculating premiums. Fairly accurate data are available on changes in life expectancy in the United States.[8]

Shortly after the Constitution was written, in 1789 to be exact, life expectancy was estimated to be 35.5 years for parts of New Hampshire and Massachusetts. In 1850 it rose to 40 (for Massachusetts) and for the United States in 1900 to 50, in 1920 to 55, while in 1930 it was a fraction over 60 years. To-day it is probably 61 or 62 years. In some other countries it is more. It may go up to about 70 years. With this change wrought by science, the character of the population has altered. In the time of Washington and Jefferson there were, as always, a few very old people, but on the average our citizens were only a little more than half as old as they will be before this generation fades away. This gradual tempering of youth, during the past 150 years, with the longer memory, experience and conservatism of older people, has undoubtedly been a wholesome factor in the development of our national habits of thought and action.

The technique of dictators is to-day, as in the past, to run away with the situation by ignoring the mature judgment of the adults and aged and by pandering only to the youth of the nation. Young people are temperamentally more visionary and inclined to idolize their leaders. Flushed by enthusiasm they are less likely to carefully think out policies and probable consequences. Theirs is a tendency to action and the devil take the hindmost. Youth movements are a very important means of progress. They have glamor, but they represent only a fraction of any population and they tend to be unbalanced. It will be freely admitted that social integration is more needed in an aging nation. There is a greater range of age, of likes and dislikes, hopes and fears to be integrated into a harmonious whole. We are permitted to believe that nature makes provision for it by increasing maturity of judgment.

There is another important point. Fairchild[9] remarks upon the leveling off of the population. "There are more than 1,600,000 fewer children under 10 now than there were five years ago." He quotes figures by Kuczynski. The figure 100 is taken to indicate a net reproduction, sufficient to maintain a population without increase or decrease. The estimates are for: England and Wales, 88; Germany, 89; France, 93.7; United States (1934), 100.

We observe, probably with some surprise, that France appears to be contracting, as far as number, less rapidly than Germany. Goebels may call for 10 million, 20 million, nay even for 30 million more Germans, but he is tilting against a whirlwind. He can retard the process of contraction just a little and very temporarily, for it is at best a long-range task; but, save by forceful annexation of additional Germans, it is safe to say that he can not materially alter this fundamental process.

Turning to the United States, Kuczynski believes that we have already embarked upon a phase of population decrease; that is to say, the figure has sunk below 100. If checked at the right time, this leveling is really a great blessing attributable to a common-sense realization of social values, though some may, at first sight, be fearful and fail to penetrate the disguise. Evidently it means

[8] Details given by L. I. Dublin and A. J. Lotka, "Length of Life—A Study of the Life Table." New York: Ronald Press, 1936.

[9] *Harper's*, May, 1938.

that we are mercifully delivered from the obligation of providing for a larger and larger population and can devote our attention to striving for quality.

Therefore in any penetrating consideration of science and social values it is necessary to be realistic and to remember that the adjustment is one of an aging population which is not expanding numerically. For several reasons we are insistently brought back to a study of the aged among us. When there are not enough jobs to go around it is the aged, the women and the children who are deprived of them first.

We know that there is a general tendency to retire elderly people from employment earlier, to make room for those in the prime of life; but accurate figures are difficult to find. However, it is reliably reported that of almost 500,000 persons on relief those between 25 and 35 were taken off the relief rolls and found reemployment in the proportion of 2 to 1 as compared with others between 35 and 45. The latter have only half a chance. How small, relatively, must be the opportunity of men and women from 45 to 55, who are not classed as old people and who are below the usual retiring age.

Another significant fact is the discovery that in the past 50 years the percentage of gainfully employed women in the United States has increased from 14.5 to 22 per cent.[10] Because the ratio between the sexes remains about the same, and the increase can not be wholly attributed to the opening up of new kinds of work, there must have been some displacement of males, especially in certain walks of life in which women are more efficient than men and work by them is a social asset. Our fathers were content with attractive male secretaries, but we are not. Who would want a male nurse? Male telephone operators are seldom in the running. Elaboration is desirable, but time does not permit. It can be said, also, that opposition from some quarters to legal restrictions on child labor is not unrelated to a hard-boiled desire to hold a larger number of jobs open for adults. In unemployment there are many factors besides labor-saving devices. Volumes are written about them.

Social adjustments to meet the impact of applied science have been woefully neglected and are just now in the making. It is no exaggeration to say that the greatest untouched problem is to find out by sustained investigation how people past maturity, who constitute such a large fraction of the population, can help us, and to profit by their efforts. To go ahead, without their cooperation, is lop-sided and short-sighted.

What, however, do we find? Men and women still vigorous and useful are forced to take a back seat. Hundreds of millions of dollars are appropriated annually to keep the unfortunate among the aged from actual want. This is really conscience money. We know that they suffer in mind and body, and to pay them a small dole is the easiest way out for us. They are all right in their place. We shrug our shoulders, thinking death is inevitable anyway and nothing can be done about it. Seldom do we trouble to explain this neglect. The aged are taboo. We turn from them to beautiful, starry-eyed children full of promise for the future. Let us not forget that those past 60 or 65 are the problem children of science, needing care and capable of making great contributions to social values.

Now for the future. Here the best of scientists become unscientific. They know it, and hence are reluctant to hazard opinions which may be dished up to them when things happen differently later. To estimate in advance the influence of any scientific discovery on our aging and slowly shrinking body politic, one must have the wisdom of a Solomon.

[10] W. E. Weld, *New York Times*, April 20, 1938.

Take the telephone. My father told me that Alexander Graham Bell offered a half share in his invention to any one at Brantford, Ontario, who would give him $100 for expenses. But the idea seemed so incredible that nobody was ready to risk this amount in such a wild-cat scheme. The worthy citizens of Boston 53 years ago thought that they acquired merit when one of their newspapers felicitated the police for arresting a criminal on the charge of "extorting funds from ignorant people by exhibiting a device which he says will convey the human voice over metallic wires."[11] It could be done elsewhere, but not in Boston!

What can be more important or thrilling than to peer into the future with the purpose of putting science to proper use? We think at once of President Hoover's Committee on Social Trends and of President Roosevelt's National Resources Committee. It is comforting to find that the work of the latter supports and extends the efforts of the former, that some members of the first committee have played a leading part in the second and that both have been constructive in the best sense of the word.

We have time to consider only a few of the conclusions reached by Roosevelt's Committee. It concerned itself with those inventions likely to exercise a profound influence on manner of life and employment within the next twenty years. The mechanical cotton picker is placed by the committee at the head of the list. The danger is fully appreciated both by the inventors and by the thinking public. Professor Ogburn is quoted[12] as follows: "Will the surplus labor of the South flood the Northern and Western cities? . . . The influence on Negroes may be catastrophic. Farm tenancy will be affected. The political system of the Southern States may be greatly altered," etc.

The production of artificial cotton from plant cellulose is listed, after careful deliberation, as another possibility. This, if done cheaply, may deliver another body blow by displacing natural cotton and the mechanical picker.

The feasibility of constructing steep flight airplanes has, the committee believes, been proved. Planes which can take off and alight in the back yard will change the whole problem of transport and serve to overcome city, state and national boundaries. The frame of things will certainly become disjointed.

Think what the 25,000,000 motor cars now in use have done for us. Yet in 1900 a newspaper congratulated Theodore Roosevelt for his "characteristic courage" in venturing to ride in an automobile. And in 1908 J. P. Morgan and Company declined to pay $5,000,000 for securities which were later incorporated in General Motors and rose to $200,000,000. There are many surprises in store for us.

The greatest danger is that, in the regulation of science to extract the greatest social value and, at the same time, to prevent dislocation, human activities may be so drastically regimented that liberty and individuality will be lost. Unhappily mechanical science is impersonal; instead of emphasizing human values, it breeds a conception of the insignificance of human beings. In one dictator nation the claim is made that unemployment is solved. It is really hidden by creating socially useless work in the army, by depriving women of the position gained a generation ago and by ruthlessly displacing a racial minority.

What must we do? All this is rather a bleak picture of science and social values, but there is always the bright side. I could sing a hymn of praise to science, but that is not my present task. We obviously want science to develop, and it is our hope that it will be better adjusted to our social fabric. To say that this integration is not our job is to

11 *Reader's Digest*, August, 1937.

12 *New York Times*, July 18, 1938.

pass by on the other side. It is for university people to come out of the cloister, to take a helpful interest in government and in education beyond our doors.

The first sentence of Carrel's declaration will bear repeating. He spoke about the enormous advances in the chemical and physical sciences of inanimate matter as compared with those in biological science. But the most telling pronouncement is that of Charles W. Eliot, long president of Harvard and himself a chemist: "The human race has more and greater benefits to expect from successful cultivation of the sciences, which deal with living things, than with all the other sciences put together."[13] We need to know more about life in all its aspects, for it is our lives which must be adjusted to the march of time and mechanical science.

The strategic thing is to start at the bottom and to build up. According to Dr. Riddle of the Carnegie Institution, the teaching of biology in the public schools is about 30 years behind the times and is falling off in quality and quantity.[14] The intellectual freedom of the teachers is at stake. They are hired and fired by the local school boards. Riddle states that "During the past 17 years five states (if we include Utah) have passed laws which prohibit the teaching of evolution in their public schools." Mention can be made of biologists who have been discharged, but to do so is not politic. The states are: Tennessee, Arkansas, Mississippi and Florida. In Utah the restriction is less drastic. Lest you take comfort in the belief that it is only in these states that teachers are told what they must and must not teach, allow me to quote from a declaration by the principal of one of Philadelphia's leading high schools. He is reported[15] in a Philadelphia newspaper of August 13, 1937, as saying in part:

> The old theory of evolutionists as to whether man is descended from the monkey has been over these many years. Such teaching is discredited and is not representative of science and so will not be found in our textbooks.
>
> The public schools teach biology. In this study, the difference of the species is indicated.
>
> The difficulty in teaching science often has been that it has been approached with an irreligious attitude. There is no such attitude among the public school teachers of Philadelphia.

It is hardly necessary to point out that the conception of evolution of man, not from the monkeys of to-day but from other animals long ago, is a fact. To set the human species apart as fundamentally different from all animals who also have certain hereditary endowments and must breathe, eat and drink and adapt themselves to their environments is to inhibit progress. Much of our knowledge about man is derived from close comparison of the species with other animals. Religious attitude has nothing to do with it. That is a personal matter concerning which there should be no dictation to our public school teachers. The principal has misstated the concept of organic evolution, has outlined a course of instruction which is scientifically unsound and has raised a bogey of irreligious attitude which does not exist.

Riddle believes it "unquestionable that it was traditional religion that has invoked the heavy hand of legislation" and speaks about guidance by the "dead hands of the past."

In every walk of life there are the narrow-minded, the bigoted and the fearful. But in the church to-day are many of our most socially minded and far-sighted citizens. Great is their faith in the rising generation. They welcome the fruits of scientific discovery. Not demoralization but clarification results. Surely it is fitting for these great preachers of the gospel of good tidings to take the field and use their influence to pre-

[13] Oscar Riddle, *Science*, April 29, 1938.

[14] *Ibid.*

[15] *Philadelphia Evening Bulletin*, August 13, 1937. See note 13.

vent the passage of any more such laws and to repeal those already in force. Their brothers in Germany have given a fine example of courage in fighting for freedom of teaching in the churches, while scientists, be it said to their shame, have merely bowed to authority in the universities.

The position of the 40,000 or more teachers of the life sciences is a disgrace. They, and the others, are shamefully underpaid. It is stated that 250,000 teachers in the United States were paid less than $750 each last year.[16] Laborers building motor cars are better paid than people charged with building the mentality of citizens of the United States. It is not money we lack, but perspective in social values. It will be a long time before teachers are given a chance to live decently, because they are not a pressure group and never will be. They are willing to serve the nation in this most important task of giving the rising tide of several million youngsters a true but necessarily elementary conception of life in all its main aspects. It appears to be an inexorable law that no teacher, much less a professor, gets a raise in salary beyond a pitiably small amount, unless under threat of quitting his job, and there are many ready to take his, or more often her, place.

What concretely can be done for this great group of teachers? At present they are unorganized, isolated from their fellows and find it very difficult to keep abreast of the times. The Carnegie Corporation of New York, through the Carnegie Foundation for the Advancement of Teaching, has come to a realization of their plight and has financed a study of the situation by a grant of $10,000 to the Union of American Biological Societies. The work is in charge of a committee of the union headed by Dr. Riddle and a National Association of Biology Teachers is being formed.

[16] *St. Louis Post-Dispatch*, March 26, 1938.

But the teaching of the life sciences, however excellent, is not sufficient. We must somehow get over to these children, who will take our places, an idea of ethics, of the right thing to do. This ethics must be superior to our own, for there is evidence that we have lost ground, as compared with our fathers and mothers. They were more apt to stay at home, to live their lives in smaller communities where they were well acquainted and where most misdeeds or unkindnesses affected people they knew and liked. Moreover, they were easily found out, and honesty was clearly the best policy.

Now, we hurry from place to place, meet a great many people whom we never get to know well, and for whom we do not feel the same personal responsibility. To steal from a passerby on the highway is ethically as bad as for Jones to steal from his friend Smith next door in a small village. The thief on the highway, however, has a far better chance to get away with it.

An impressive statement could be made of the increasing cost of crime. What I wish to stress, however, are the intangibles; not the anti-social but the unethical, if there is a real difference between the two. It used to be said that "a man is so mean that he does not even pay his taxes." To-day, tax evasion is a fine art. Ghost voters are frowned upon; but we all know with what complacency some of our leaders pass off as their own the work of ghost writers. And the socially elect give advertising testimonials for products which it is doubtful whether they ever use. With apparently increasing ease we protest less and less about actions we know to be wicked on the basis of "the mind your own business" policy. This anti-social attitude is considered a virtue and some are proud of it.

Years ago in England there were, as now, cases in which operation of the legal machinery did not achieve ethical ends.

The King stepped in and followed the dictates of his conscience, which was called "equity." The word is still with us; but decisions, on the basis of equity, are strictly limited. Right and fair dealing are often subordinated to legal technicalities.

We are becoming callous to human suffering as long as we do not see it before our eyes. The vicious doctrine that the end justifies the means is condoned. The savagery with which scientific discoveries are utilized to destroy social values in warfare has increased to a dreadful extent. The concept of social responsibility between peoples embodied in the Covenant of the League of Nations is repudiated. The Neutrality Act is anti-social, since in operation it gives comfort and actual help to the aggressor. The invasion of China is carried on with the aid of California oil.

The only ethical justification for neutrality is ignorance. When the facts become known in any dispute we are obliged, unless we are wholly anti-social, to form an opinion and to act to the best of our ability. To refrain from expressing this opinion; because, for selfish motives, we do not wish to be drawn into the controversy is to be unethical. Yet how often do we simply shrug our shoulders and say we haven't time? All of us can not be uplifters; but the basis of public ethics must be broadened and, in shaping it, the higher education given in our universities should supply some leaders.

Is the slump in ethics another manifestation of failure to adjust ourselves to the onrush of science? I think it is. We can speak thousands of miles and our actions are felt around the world. Our sphere of influence has, however, expanded out of all proportion to our sense of responsibility. We find it difficult to catch up with the results of what we do individually and nationally. The tragedy is that we do not care very much as long as no harm is done in our own narrow social environment. For the isolationists this environment is contracting.

Coming back to our thesis, it can be said that the proper use of scientific discovery, having in mind its social value, is our mainstay. To hold to it is very difficult, but I firmly believe that the life of each one of us will be richer if, in addition to dedicating ourselves to the advancement of science, we devote a little time to some specific social service which does not profit us directly, but which is designed to help our neighbors near and far.

MOTHER OF COMPTONS

By MILTON S. MAYER
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HONORARY degrees are supposed to signify achievement. Sometimes they signify the achievement of the recipient in science or the arts. Sometimes they signify (though seldom openly) the achievement of the college in wheedling a new dormitory from a prosperous citizen. A few years ago Ohio's historic Western College for Women bestowed a doctorate of laws for neither of these reasons. The recipient, whose bearing denied that a woman is old at 74, was awarded the LL.D. "for outstanding achievement as wife and mother of Comptons."

Having received this recognition of her contribution to American life, the new doctor hurried back to the welcome obscurity of an old frame house on a quiet street in the little college town of Wooster, Ohio. Otelia Compton doesn't want to be famous, and she isn't. Four of the men to whom she is wife or mother occupy a whole page in "Who's Who in America," but the larger achievement of a middle western farm girl is unrecorded.

Those who extol the virtues of heredity may examine with profit the Compton family tree. For the ancestors of the first family of science were common farmers and unskilled mechanics, and the only one of them associated with scholarship was a carpenter who helped nail together the early buildings of Princeton. True, Elias Compton and Otelia Augspurger both taught school to help support the farms on which they were born, but so had farmers' sons and daughters before them. And there was no reason to predict that the union of two country school teachers would produce a page in "Who's Who."

Nor could the naked eye distinguish in the simple Compton household a special genius in the practice of domestic wisdom. Still, the genius must have been there, for of the four children born to Elias and Otelia Compton, Karl, the oldest, is a distinguished physicist, now president of the great scientific institution, Massachusetts Institute of Technology; Mary, the second, is principal of a missionary school in India and wife of the president of Allahabad Christian College there; Wilson, the third, is a noted economist and general manager of the U. S. Lumber Manufacturers' Association, and Arthur, the "baby," is, at forty-five, one of the immortals of science—winner of the Nobel Prize in Physics.

How did it happen? The answer of the four famous Comptons is a nod in the direction of the old frame house in Wooster. In the "sitting room" at Wooster I found Elias Compton, beloved elder statesman of Ohio education, who died last May at the age of eighty-one. He taught philosophy at Wooster College for forty-five years. But I did not find the answer to my question in the sitting room, for the father of Comptons explained that he was just one of Otelia's boys and referred me to the kitchen, where the mother of Comptons, at the age of 79, manages the home that gave America one of its most eminent families.

It is characteristic of Otelia Compton's philosophy that she should deny she has a recipe for rearing great men and women. She will admit that her children are "worthy," but what the world calls great has no significance for her. When she heard the news that

Arthur had won the world's highest award in science, her first words were. "I hope it doesn't turn his head." In the second place, she refuses to be an expert and has never before permitted herself to be quoted on the secret of successful motherhood. The only way I was able to pry her loose from her reticence was to get her into a good hot argument.

That was the weakness in her armor. For this doctor of laws actually has a set of laws, and to challenge them is to ask for a fight. There is nothing unfair about picking an intellectual quarrel with this woman of almost eighty years; she is more than equal to it. She reads as ardently as any scholar. She thinks as nimbly as any logician. And her youthfulness is such that when, one day this summer, she forgot to take off her wrist-watch before her daily swim, her children kidded her about getting old.

She may disclaim her expertness, but her record is against her. There are her four children, with their total of thirty-one college and university degrees and their memberships in thirty-nine learned societies. They didn't just grow. In addition, there are the hundreds of boys and girls whose lives Otelia Compton shaped during the thirty-five years she spent directing the Presbyterian Church's two homes for the children of its missionaries. Cornered in her kitchen, the mother of Comptons simply had to admit that she knows something about motherhood.

Her recipe is so old it is new, so orthodox it is radical, so commonplace that we have forgotten it and it startles us. "We used the Bible and common sense," she told me. I replied that "the Bible and common sense" was inadequate, since the Bible has been misused by knaves and common sense is an attribute every fool imputes to himself. She looked at me hard through her gold-rimmed glasses. Slowly her gray eyes softened. She smiled, and told me to go ahead and tell her what I wanted to know.

The first thing I wanted to know was, "How important is heredity?"

"That depends on what you mean by heredity."

"Well," I said, "let's say 'blue blood.'"

That was easy for the descendant of Alsatian farmers. "If you mean the principle that worth is handed down in the bloodstream, I don't think much of it. Lincoln's 'heredity' was nil. The dissolute kings of history and the worthless sons and daughters of some of the 'best families' in our own country are pretty good evidence that blood can run awfully thin. No, I've seen too many extraordinary men and women who were children of the common people to put much stock in heredity.

"Don't misunderstand me. There is a kind of heredity that is all-important. That is the heredity of training. A child isn't likely to learn good habits from his parents unless they learned them from their parents. Call that environment if you want to, or environmental heredity. But it is something that is handed down from generation to generation."

In connection with misplaced faith in heredity, the mother of Comptons has something to say about the notion held by so many to-day that their children "haven't got a chance." It is a notion, she feels, which is becoming entirely too prevalent. "This denial of the American reality of equal opportunity," she said, "suggests a return to the medieval psychology of a permanently degraded peasant class. Once parents have decided their children haven't got a chance, they are not likely to give them one. And the children, in turn, become imbued with this paralyzing attitude of futility."

Certainly the four young Comptons would never have had a chance had their parents regarded economic hardship as insuperable. Elias Compton was earn-

ing $1,400 a year as a professor while his wife was rearing four children and maintaining the status a college community demands of faculty households. The children all had their chores, but household duties—and here is an ingredient of the Compton recipe—were never allowed to interfere either with school work or the recreation that develops healthy bodies and sportsmanship.

If heredity is not the answer, I wanted to know, what is?

"The home."

"That's a pleasant platitude," I said, in an effort to draw my "opponent" into the middle of the ring. I succeeded.

"It's a forgotten platitude," she replied sharply. "The tragedy of American life is that the home is becoming incidental at a time when it is needed as never before. Parents forget that neither school nor the world can reform the finished product of a bad home. They forget that their children are their first responsibility.

"To-day servants are hired to take care of children. In my day, no matter how many servants a mother could afford she took care of her children herself.

"The first thing parents must remember is that their children are not likely to be any better than they are themselves. Mothers and fathers who wrangle and dissipate need not be surprised if their observant young ones take after them. The next thing is that parents must obtain the confidence of their children in all things if they do not want to make strangers of them and have them go to the boy on the street corner for advice. Number three is that parents must explain to the child every action that affects him, even at the early age when parents believe, usually mistakenly, that the child is incapable of understanding. Only thus will the child mature with the sense that justice has been done him and the impulse to be just himself.

"The mother or father who laughs at a youngster's 'foolish' ideas forgets that those ideas are not foolish to the child. When Arthur was 10 years old he wrote an essay taking issue with other experts on why some elephants were three-toed and others five-toed. He brought it to me to read, and I had a hard time keeping from laughing. But I knew how seriously he took his ideas, so I sat down and worked on them with him."

Arthur—he of the Nobel Prize—was listening to our conversation, and here he interrupted. "Mother," he said, "if you had laughed at me that day, I think you would have killed my interest in research."

"The reason why many parents laugh at their children," Mrs. Compton went on, "is that they have no interest in the child's affairs. The mother and father can not retain their influence over their children if their children's life is foreign to them. And it isn't enough to encourage the child; the parents must *participate* in his interests. They must work *with* him, and if his interest turns out to be something about which they know nothing it is their business to educate themselves. If they don't, the child will discover their ignorance and lose his respect for them."

When Karl Compton was twelve, he wrote a "book" on Indian fighting. Mary was absorbed with linguistics. Wilson's devotion to the spitball made him the greatest college pitcher in the Middle West. Arthur, too, was a notable athlete, but his first love was astronomy. The combination of Indian fighting, linguistics, the spitball and astronomy might have driven a lesser woman to despair, but Otelia Compton mastered them all as she did their other diversions. For instance, the summer the Compton family caught 1,120 pounds of fish, mother landed her share.

All the toys the young Comptons had could have been bought for a few dollars, but when the four of them were still

under ten years of age their mother packed them up, together with a father who had almost died from pneumonia, and took them to the wilds of northern Michigan, where mother and children hewed a clearing and pitched a tent. There these urban-bred children learned simplicity and hard work. There they found that the things which tempt children need not be forbidden them when those things are fishing and woodcraft and the stars. There they imbibed, as the mother of Comptons would have every city child imbibe, of the unity and mystery of nature.

The boys all worked summers and in college, gaining priceless experience; and they all had their own bank accounts, "not," their mother explains, "because we wanted them to glorify money but because we wanted them to learn that money, however much or however little, should never be wasted." Would she put hard work first in her lexicon? Mrs. Compton thought a moment. "Yes," she said, "I would. That is, hard work in the right direction. The child who has acquired the habits of work of the right kind does not need anything else."

And what is the "right kind" of hard work?

"The kind of work that is good in itself."

I baited the trap. "What's wrong with working for money?"

The mother of Comptons exploded. "Everything! To teach a child that money-making for the sake of money is worthy is to teach him that the only thing worth while is what the world calls success. That kind of success has nothing to do either with usefulness or happiness. Parents teach it and the schools teach it, and the result is an age that thinks that money means happiness. The man who lives for money never gets enough, and he thinks that that is why he isn't happy. The real reason is that he has had the wrong goal of life set before him."

What did she mean by parents and schools "teaching" that money is happiness?

"I mean all this talk about 'careers' and 'practical' training. Children should be taught how to think, and thinking isn't always practical. Children should be encouraged to develop their natural bents and not forced to choose a 'career.' When our children were still in high school, a friend of ours asked Elias what they were going to be. His answer was, 'I haven't asked them.' Some of our neighbors thought we were silly when we bought Arthur a little telescope and let him sit up all night studying the stars. It wasn't 'practical.'" Yet it was his "impractical" love of the stars that brought him the Nobel Prize and something over $20,000; and in order that he might pursue his cosmic ray research, the University of Chicago equipped a $100,000 laboratory for him.

I thought of the four Comptons and the success that has resulted from their early training, and I wondered if "impractical" parents weren't perhaps the most practical. What could be more tangible than the satisfaction and the honors that have come to them because of their far-flung labors?

COMMENTS ON CURRENT SCIENCE

By SCIENCE SERVICE[1]

WASHINGTON, D. C.

CHEMISTRY AND PHYSICS IN AID OF HEALTH

One of the brightest spots on the picture of to-morrow's health is being painted in to-day by chemists and physicists working with physicians and other medical scientists.

The x-ray was an early important contribution of physics to the healing art and science. The tagged atom of artificially radioactive material, made in the atom-smashing cyclotron, is the latest such contribution. X-rays enable physicians to see inside the body, to see broken bones, ulcers and even cancers of internal structures. Tagged atoms are helping scientists to trace the distribution of various chemicals in the body tissues and to learn more of how they are utilized.

On the chemical side, advances lately have also been very rapid. Sulfanilamide was for a long time just a waste product in the dye industry. Then suddenly, under the guise of Prontosil, it burst upon the medical world as a remedy for childbed fever. That was only yesterday. To-day sulfanilamide is on every one's tongue because it has become an effective weapon against erysipelas, scarlet fever, meningitis, gonorrhea, streptococcus throat infections and even pneumonia. In addition, sulfanilamide has started a fresh wave of search for chemical remedies for many ailments.

It is not only by the discovery of new remedies that chemists are helping physicians to improve the health picture. Speaking on this point, Dr. Stuart Mudd, of the University of Pennsylvania, recently said: "A striking aspect of recent medical progress is that both normal physiological processes and the abnormal process of disease are finding explanation in terms of the chemical substances responsible for them."

[1] Watson Davis, director, Frank Thone, Robert D. Potter, Jane Stafford, Emily C. Davis and Marjorie Van de Water, staff writers.

WORLD INQUIRY INTO SOCIAL EFFECTS OF MODERN SCIENCE

A world inquiry into the part that science plays in modern society is under way and will come to fruition, the international situation willing, probably in 1940. It is the work of the Committee on Science and its Social Relations (C.S.S.R.) instituted by that closest approach to a world super-government for science, the International Council of Scientific Unions, in May, 1937.

Using elaborate questionnaires as a mechanism, a fact-finding campaign is being conducted through the agencies of nationally representative scientific organizations of the various countries. In America, this would be the National Academy of Sciences; in Britain, it would be the Royal Society of London.

There will also be special inquiries along specialized lines, with questionnaires for mathematics, astronomy, mechanics, physics, chemistry, biology, geophysical sciences, geography. Because some fields are not represented by the unions that compose the International Council, the medical and engineering sciences, agriculture, sociology and economics are not being included in the first inquiries.

The organization of the international inquiry is in the hands of Professor J. M. Burgers, of Delft, Holland, secretary of the C.S.S.R. In addition to the official questioning and compiling contemplated,

there is a place in the plans for assistance from individual scientific investigators. Such points as these, it is felt, might be answered more effectively by individual than by official organizations:

(1) The part played by scientific thought in the outlook of various social groups.

(2) The forms in which scientific workers and their work are involved in the various struggles and conflicts of human society.

(3) The forms in which the consciousness of a social responsibility of science and of scientific workers is taking shape.

These are matters of extreme importance in the large vistas of the world. If they seem less important than fast-marching current affairs, it is largely a matter of perspective. The fear is that the forces of violence will throttle the opportunity of such deliberate assaying of the science that has made civilization.

NEW COSMIC RAY PARTICLE

THE physicists have nearly as much trouble naming a new fundamental particle as a family of fond parents, grandparents and in-laws deciding what to call a new baby.

Now it is the heavy electron, the particle that lives only about a millionth of a second after being born of the cosmic rays, that is being christened enthusiastically.

Americans are calling the heavy electron "baryton," the first part of the word being Greek for "heavy." But Europeans, with Professor Niels Bohr, of Copenhagen, as chief protagonist, are using "yukon" in honor of the Japanese physicist, Yukawa, who postulated the existence of the particle before Drs. C. D. Anderson and Seth Neddermeyer, of Pasadena, discovered it in 1937.

In discussion at the recent Cambridge meeting of the British Association, one of the Americans present observed that yukon was a rather cold name for a particle so hotly discussed and that Alaskans might protest.

The heavy electrons seem to make up the major portion of the penetrating particles resulting from the cosmic radiation. Scientists are flying high into the atmosphere and setting up apparatus deep in tunnels in order to study them.

With some 240 times the mass of the ordinary electron, basic unit of electricity, the heavy electron is lighter than the proton, the nucleus of the hydrogen atom. It may very well be triplets, for it would be logical for it to be found with negative and positive charges as well as no charge at all.

It is a very unstable creature, existing theoretically for a mere millionth of a second when at rest. Strangely enough, it lives longer when it goes fast, owing to the relativistic change in time. One of them by great good luck was photographed at Pasadena coming to rest. Heavy electrons are supposed to disintegrate into electrons and neutrinos. And neutrinos are particles postulated but not yet discovered.

SOAP BUBBLES AND EXPLOSION STUDIES

AT the National Bureau of Standards in Washington Uncle Sam's scientists have been blowing bubbles in the laboratory and learning new secrets of how explosions occur in gases. Particularly they have been seeking to learn how fast a flame from an explosion will speed through space, a matter intimately tied up with explosive fires and indirectly with the efficiency of internal combustion engines.

Scientists Ernest F. Fiock and Carl H. Roeder, in a report prepared for the National Advisory Committee for Aeronautics, outline their methods of soap-bubble blowing and why it has value in combustion and explosive research projects.

The trick is to blow a soap bubble

with an explosive gas, such as carbon monoxide, and make it form around a gap between two metal wires. Across this gap an electric spark can be made to jump, ignite the gas and create the explosion. Just as the explosion is to occur a high speed motion picture camera, taking over 1,600 frames a second, goes into operation and photographs the progress of the flame.

Key point of the soap bubble method is that it occurs essentially in free or unconfined space, because the soap film expands very easily to any pressure increase. As a matter of fact, the method is said to give results under constant pressure and at the same time enables the direct observation of the relative speeds of the flame and the expanding, but yet unburned, gases.

For explosions of carbon monoxide it was found that flame speeds reached values of 900 centimeters per second or about 20 miles an hour.

The soap bubble method has been a pioneering effort in the broad study of gaseous explosions. The general project is being continued, says Mr. Fiock, by additional methods which should have an even wider range of applications.

MALNUTRITION AMID FOOD PLENTY

THERE are thousands of Americans who live in a land of food plenty and yet suffer from hunger. This is not a story about economics and how badly we distribute our agricultural products. It is a story of hidden hunger, the diseases of malnutrition. It is an ABC story because it is about vitamins.

The best estimates or guesses as to the prevalence of nutrition diseases can not be backed up by figures because, except for pellagra in some southern states, the deficiency diseases are not reportable. Yet people die of them.

The prize medical story in this regard comes from one of the largest of New England cities. A woman was found dead at the bottom of a staircase in a not-too-well-off residence. She was covered with what appeared to be livid bruises. Naturally the husband was taken into custody by the police. He might have been tried for murder, except that a keen-eyed coroner-physician, performing the autopsy, rendered a verdict that set him free. The woman had died of acute scurvy, the symptoms of which made her appear to have been badly beaten. Scurvy is caused by a lack of vitamin C contained typically in citrus fruits.

Lack of vitamin A causes a form of night blindness, sometimes involved in auto accidents. This vitamin is contained in butter. When during the world war, no butter was available and skim milk was used widely in some Scandinavian areas because butter could be sold at such high prices, eyes of some children were permanently injured.

Rickets is widely found in rich and poor children alike, despite all the cod-liver oil and vitamin D extracts sold and administered.

All the pellagrins, those who do not get the P-P factor that prevents pellagra, are not in the southern states. It is found in northern areas and large cities where lack of money, alcoholism or idiosyncrasies of diet prevent eating proper protective food.

Beri-beri is occasionally found in America. Its cause, which is lack of vitamin B one, is also blamed for neuritis frequently associated with other diseases in this country.

CORROSION WASTES

THE war-basis budgets of the nations of the world reach staggeringly large figures, but the most costly single item which the United States or any other nation faces is the cost of corrosion and its prevention.

This is the estimate of C. E Heussner.

materials engineer of the Chrysler Corporation, who computes the world cost of the corrosion damage of metals alone at some $5,000,000,000 each year.

Each year a quarter of all the iron in the world returns to oxides or ores from which it came, Mr. Heussner states in an American Society for Testing Materials summary.

Much of the iron thus corroded is lost permanently, for while it is theoretically possible to send the iron oxide back to a plant and convert it into commercially pure iron again, the iron rust is so scattered that it is economically useless to collect it and start over again. It is only economical to try and collect the unrusted parts of scrap metals. Hence the place of the junkman in modern society.

Speaking rather loosely, we talk of rust-proof metals and corrosion-resistant materials, but in actual fact all metals and protecting surfaces fall down in special cases and what is good for one job is useless in another. Everything depends on a metal's environment, the conditions under which it will be used in service.

Ordinary steel, as one example, needs plenty of protection. It rusts in moist air and dilute nitric acid. But if steel is immersed in concentrated nitric acid—a potent solvent—it will not dissolve. The steel becomes passive and acts like a noble metal. In this environment steel *is* a noble metal, H. W. Gillett, of the Ohio State University's Battelle Memorial Institute, observes in another part of the report on corrosion.

FORESTS FOR AMERICA'S FUTURE NEEDS

During the past ten years a quiet revolution has taken place in this country. It has little or nothing to do with the socio-political field—there has been a revolution there, too, if you like; but nobody could claim it was a quiet one.

Our quiet revolution, nevertheless, affects the lives of all of us and will continue to do so for a long time to come, for it is in the field of forestry. Ten years ago Congress enacted the McSweeney-McNary bill, which placed forestry research in this country on a solid, systematic basis. This month, foresters are celebrating the decennial of their Magna Charta, and a special issue of the *Journal of Forestry* is devoted to a discussion of scientific progress in all branches of forestry during that period.

There is a lot more to forestry than just going out and planting a lot of new trees where old ones have been cut down. Managing a forest is a more complex job than managing a factory—or even a whole chain of factories, for forest products cover a range all the way from timbers and turpentine to such intangible services as watershed protection and fun for fishermen. And forest research must take all these things into account.

Basic idea of the research program is stressed by Dr. Earle H. Clapp, associate chief of the U. S. Forest Service:

> The Act and the various things that have grown out of it have helped drive home the concept that the forest of any area is a biological entity, all the elements of which are integrated with all the others and are influenced by them,
>
> The biological elements of the forest of an area or region extend in the same way into the social and economical field. All of this exceedingly complex interrelationship has emphasized the need for conducting research on the basis of these relationships, or in brief, the need for cooperation by groups of specialists in coordinated, well-rounded-out many-sided attacks in contrast with isolated and purely individual work.

THE RICHMODIS LEGEND OF THE PLAGUE

By Dr. IVAN C. HALL

UNIVERSITY OF COLORADO SCHOOL OF MEDICINE AND HOSPITALS, DENVER

THE gray air balanced the tone of the bell on Apostle's Church as it, like every other church bell in Cologne, sounded the hour.

The city was ravaged by plague and the terrified people, bending their backs as if under a scourge, cursed the year 1357, for they were dying like flies in autumn. In vain, the priests preached resignation; the sanctuaries were empty and people went about as if they were all afflicted with the fatal germ, while the grave diggers shoveled day and night.

One morning the toll of the bell on Apostle's Church was prolonged. At Neumarkt Platz fearful faces peered from half-opened doors; the news flew from mouth to mouth, from porch to porch. "The one who is dead, who has been carried away this very hour, is no other than Frau Richmodis. What a pity, with all the accumulated grief and sorrow! The rich, the beautiful, the good, young, lovable Frau Richmodis! The horrible plague makes no distinction!"

"It is no brilliant cortege with long procession to dignify a lady which suddenly leaves the house of death, but four black men, who carry a long box. They hasten rapidly from the place. Do they not fear the dead, who may give them death, the horrible death?"

Herr Richmodis followed them to the grave, saw his lovely Frau sink into it, and heard the first clods of earth as they fell on the coffin. He also heard the loud sobbing of the poor people whom Frau Richmodis had helped so much. Then he returned to his beautiful home, now empty and lonely.

The two grave diggers paused to rest when the people had gone. Said one to the other, "Isn't it a sin and a shame that so costly a ring with its sparkling diamond and all that gold should remain buried in the ground?" And so they returned that night, and opened the grave, to steal the valuable trinkets. But when they removed the lid of the coffin Frau Richmodis awoke with a deep sigh and slowly sat up, whereupon the grave diggers dropped their lantern and fled into the dark night for their very lives.

FIG. 1. THE OLD RICHMODISHAUS IN FRONT OF APOSTLE'S CHURCH IN COLOGNE, SHOWING THE HORSES' HEADS. THIS BUILDING WAS TORN DOWN IN 1927 TO MAKE WAY FOR A MODERN OFFICE BUILDING.

Pale and weak in her white shroud, Frau Richmodis found her way with the aid of the lantern along the death-still street to her own house. She rang the bell until finally a servant maid opened a window and recognized her mistress. Horrified, she slammed the window shut and was barely able to tell her master that his Frau was at the door. Said he, "It is not possible! I would as soon believe that my two horses would leave their stalls to go up the stairs and stick their heads out of the second story window." Hardly were these words spoken before the trampling of horses' hoofs was heard on the stairway. Herr Richmodis ran as quickly as he could, and, sure enough, there was his good Frau before the door. In a few days, with rest and food, she was as fresh and rosy as before. She lived a long time and had a large family.

Such is the Richmodis legend of the plague. For many years this legend was perpetuated by two carved horses' heads peering from the top story window of the vine-covered Richmodis house, which is here illustrated before the bell tower of the Apostle's Church (Fig. 1). This famous old house was demolished in 1927 to make way for a modern office building, but the tourist still sees the horses' heads high up on the face of it and hears the story from the sightseeing bus in Cologne (Fig. 2).

I am indebted to Herr D. E. Alsberg, of Richmodishaus, for the illustration, for a loaned copy of "Richmodis von Aducht" by M. Kaster, illustrated by Erika Freund, as well as a clipping from *L'Eclaireur du Soir*, December 10, 1931, from both of which the above was freely translated.

FIG. 2. THE NEW RICHMODISHAUS ON NEUMARKT PLAZA, AN ARROW SHOWING THE POSITION OF THE HORSES' HEADS.

THE PROGRESS OF SCIENCE

THE SCIENTIFIC MONTHLY AND THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

At the April, 1925, meeting of the executive committee of the council of the American Association for the Advancement of Science, the editor and owner of *Science* offered under certain conditions to let the journal, which since 1900 had been the official organ of the association, become its absolute property. The plan was approved by the executive committee, which unanimously voted "its sincere and hearty thanks to Dr. Cattell for his most generous offer." The agreement was put in contractual form by Dr. Roscoe Pound, dean of the Harvard Law School, one of the distinguished fellows of the association, originally elected for his contributions to botany. The contract was executed by the owner of *Science* and Dr. Pupin, president of the association, and attested by Dr. Livingston, permanent secretary, on July 28, 1925. It was approved by a unanimous vote of the council of the association on December 30, and a committee, consisting of Drs. Pupin, Kellogg and Livingston, was appointed to express to Dr. Cattell the appreciative thanks of the association.

At the annual meeting of the association held in Atlantic City in December, 1936, a similar offer was made in regard to THE SCIENTIFIC MONTHLY, which has been an official journal of the association since 1907 to the extent that it may be received by members in place of *Science*. The offer was referred to a subcommittee consisting of Professor Edwin G. Conklin, president of the association; Professor George D. Birkhoff, president-elect; and Professor Burton E. Livingston, formerly permanent secretary. This committee reported to the executive committee meeting in New York in April, 1937, as follows:

> The subcommittee is unanimously agreed that Dr. Cattell's proposal is a very generous one and that it will be of much present value to the association and may in the future become of still greater value. We, therefore, recommend that it be adopted with hearty thanks and that the President and Permanent Secretary of the Association be authorized and directed to take such steps as may be necessary therefor and to enter into and to execute a contract for this transfer of THE SCIENTIFIC MONTHLY from its present owner to the American Association for the Advancement of Science, in conformity with the terms of the proposal of Dr. Cattell dated December 25, 1936, and that this action be reported to the council at the Denver meeting. We also wish to express to Dr. and Mrs. Cattell our sincere appreciation of their great and long-continued services to scientific organization, cooperation and progress.

This report was unanimously approved by the executive committee and was reported to the council at the Denver meeting. In view of this action it was decided last spring to let THE SCIENTIFIC MONTHLY be edited at the Washington office of the association, and Dr. F. R. Moulton, permanent secretary of the association, and the late Dr. Earl B. McKinley, member of the executive committee, agreed to join in the editorship, Ware Cattell remaining as associate editor. Manuscripts and other editorial communications should now be sent to The Editors of THE SCIENTIFIC MONTHLY, Smithsonian Institution Building, Washington, D. C.

THE SCIENTIFIC MONTHLY, then named *The Popular Science Monthly*, was established by J. W. Youmans and the firm of D. Appleton and Company in 1872. In its earlier years organic evolution and natural selection excited controversy and wide public interest; the journal attained much influence and a relatively large circulation. The Appletons published in the United States the works of many British men of science and were able to print in the *Monthly* articles by Darwin, Spencer, Huxley, Tyndall and other lead-

ers. After the death of the elder Youmans and the development of more technical work in science the journal became unprofitable, having been conducted for a time at an annual loss of about $10,000. It was then sold to the present owner and editor.

The transfer of the journal to the American Association, combined with efficient editorship, should give the country a better journal of general science than it has ever before had. It should greatly increase the membership of the association and have the cooperation of all workers in science. There will be no change in editorial policy, but an endeavor will be made to make the journal not only authoritative, as it has always been, but of greater interest to those educated people who wish to follow the advances and share the spirit of science, the dominant factors in modern civilization.

The undertaking will be much more difficult without McKinley, who was admirably fitted for the editorship of a journal such as THE SCIENTIFIC MONTHLY. His loss with the ill-fated Hawaii Clipper, while collecting germs in the upper air for his studies on the distribution of disease, was a disaster to science the magnitude of which can only be appreciated by those who have worked with him. He was dean of the Medical School of the George Washington University and was engaged in scientific work of originality and importance. In addition to these engagements he devoted a considerable part of his time and unlimited energy to scientific organization. In recent years he has taken a leading part in the work of the American Association for the Advancement of Science and for it his loss is irreparable. As one of the editors of THE SCIENTIFIC MONTHLY he would surely have had the usefulness and the success that attended all his enterprises. McKinley had genius for scientific research, organization and administration; most of all, for friendship. There is none like him, none, nor will be.

J. McK. C.

THE RETIRING PRESIDENT OF THE CARNEGIE INSTITUTION OF WASHINGTON

AFTER a period of service of eighteen years as president of the Carnegie Institution of Washington, Dr. John Campbell Merriam will retire on December 31 of this year in order to devote his time to research in science and to writing. A research scientist, who is required to give most of his time to administrative tasks and thereby compelled to subordinate or neglect his own research activities, looks forward to the opportunity of again undertaking them in quiet and released from executive responsibilities. Provision has been made by the trustees of the Carnegie Institution to permit Dr. Merriam to do this, and he will naturally welcome freedom from the duties that rest upon the president of a large organization.

Under Dr. Merriam's leadership the Carnegie Institution has continued to grow steadily and to make many important contributions to knowledge in different branches of science. When he became its president on January 1, 1921, the institution had already established itself as an effective research agency. Founded in 1902 by Andrew Carnegie "to encourage, in the broadest and most liberal manner, investigation, research and discovery, and the application of knowledge to the improvement of mankind," the institution first sought information on problems of fundamental importance in various branches of science that could best be attacked through the cooperative efforts of groups of investigators trained in different fields. These

DR. JOHN CAMPBELL MERRIAM

problems were studied by special committees who made recommendations that led gradually to the establishment of departments of research within the institution.

The effort was also made, at the request of Mr. Carnegie, to find and to aid unusually talented men in their work. Many small grants were thus made to men over the country who had specific problems to solve. Dr. Woodward, during the early years of his presidency, examined carefully into these scattered grants and found that a surprisingly small number yielded results commensurate with the outlay. On the basis of this experience the institution gradually adopted the policy of devoting most of its available funds to support of work by its own investigators on a few large projects. A limited number of research associates of proved ability who were able to give their entire time to research work were also maintained as members of the institution; but the granting of small sums to aid in the solution of specific problems unrelated to the work of the institution was not encouraged. The institution has sought always to do scientific work of the highest quality, chiefly in experimental fields in which conclusions can be tested by laboratory experiment or by observations in the field. This method of approach is slow, but it is thorough and effective and enabled the institution to avoid many difficulties incident to early stages of development.

When Dr. Merriam succeeded Dr. Woodward as president there were eleven departments of research in the institution. They were scattered over the country and operated quite independently. This state of almost complete autonomy arose because in the early days the energies of each department were concentrated on the tasks at hand and opportunities for cooperation with other departments or with outside organizations were not emphasized; once established, this tendency toward isolation remained until Dr. Merriam sought gradually to remedy it by taking advantage of opportunities for research work requiring attack by several departmental groups or between a research group within the institution and an outside group. He visualized the institution as a unified organization devoted to the conduct of research in science and to its application to human needs.

Throughout his administration Dr. Merriam has stressed the unity of the Carnegie Institution operating through departmental groups and research associates on certain fundamental problems. This shift of emphasis from the departments to the institution itself has proved fruitful because it has provided for flexibility of planning and of coordinating attack on scientific problems to take advantage of conditions as they arose and to approach them with greater understanding. It has made possible more effective cooperation with outside agencies with resulting stimulus to creative work. It has resulted in the administrative grouping of certain departments into divisions, such as the divisions of animal biology, of plant biology and of historical research; also in the appointment of interdepartmental committees to work on special problems.

Dr. Merriam further realized the responsibility that rests upon the institution to inform the public regarding the results of its scientific activities and to interpret these results in such manner that their significance in relation to human progress may be generally understood. To meet this responsibility different steps have been taken. A public exhibition of the results obtained in certain current investigations by the institution is held each year; at this exhibition men from the departments demonstrate special phases of the work. Lectures by staff members are given in conjunction with the exhibits and at other

times during the year on special problems under investigation. Many of these lectures are published and reach a large group of readers.

The scientific publications of the institution contain part of the record of its scientific work. But these records are not read by the general public because they are too technical in form. Accordingly, under Dr. Merriam's guidance, the editor of the institution, in cooperation with staff members, has prepared for many years past accurate, readable statements on the results of work by the institution for distribution to newspapers and magazines, to staff members and to a large number of high schools. In these statements and releases serious effort is made so to present the information that the general reader will find it interesting. The problem of public relations is not easy, but Dr. Merriam's solution of it for the institution has been successful and has recently led the trustees to vote funds for the erection of an addition to the Administration Building in Washington to provide for a better lecture hall (to be called the Elihu Root Hall) and for adequate exhibition halls as well as offices and storage space. The building will be ready for occupancy before the end of this year.

Dr. Merriam has encouraged cooperative work between the institution and other organizations, especially when the combined effort has promised a better and more effective solution of the specific problems under discussion. On occasion the institution has served as an initiating and supervising agent, although the ultimate conduct of investigations thus undertaken may be under other auspices.

On retiring from responsibility for the conduct of work on these and many other problems, Dr. Merriam will carry with him the good wishes of all staff members of the institution; they have learned to look to him for advice and help and to rely upon his wise judgment in meeting situations. They realize that, in retiring, Dr. Merriam will have opportunity for important work in his own field of vertebrate paleontology and for further philosophical analysis of the meaning of science to mankind; but they will miss his constructive suggestions and his genial personality.

F. E. Wright
Geophysical Laboratory,
Carnegie Institution of Washington

THE UNIVERSITY OF NORTH CAROLINA

Assembling in Chapel Hill, N. C., for its fall meeting (October 23 to 26), the National Academy of Sciences not only makes its "farthermost south," but also becomes the guest of an "oldest state university." There are perhaps a half dozen "oldest state universities,"[1] but the University of North Carolina at Chapel Hill seems clearly to have been first to receive faculty and students, at least among those which have had any sort of continued existence as state institutions from their beginnings to the present time. Only the exigencies of war and reconstruction brought about a temporary closure from 1870 to 1875.

Authorized in the Constitution of 1776 and chartered in 1789 (not as early as some others of the "oldest"), the university began actual teaching in 1795 in a building whose cornerstone had been laid two years earlier. After a period of guidance by "presiding professors," the first president was elected in 1804. It is of interest that the terms of two presidents, Caldwell (1804–12 and 1816–35) and Swain (1835–68), spanned the entire period from 1804 almost to the closure in

[1] Dean Robert B. House, of the University of North Carolina, has already proposed the formation of a "National Society of Oldest State Universities," to comprise those institutions which severally claim to be the oldest!

VENABLE HALL, UNIVERSITY OF NORTH CAROLINA

THE BUILDING IN WHICH THE SCIENTIFIC SESSIONS OF THE ACADEMY WILL BE HELD. NAMED IN HONOR OF FRANCIS PRESTON VENABLE, PROFESSOR OF CHEMISTRY FROM 1880–1900 AND 1914–1930, AND PRESIDENT OF THE UNIVERSITY FROM 1900 TO 1914.

1870, except for a period of four years, during which President Caldwell voluntarily found escape from the honors and responsibilities of a college presidency.

Like many other universities and colleges, the University of North Carolina had exceedingly limited financial resources during most of the nineteenth century. Nevertheless, the continuing good fortune of the university in the choice of presidents and faculty created an atmosphere of devotion to scholarship. The development of its scientific departments in recent times owes much to the vision, energies and capacities of such men as Francis P. Venable, long professor of chemistry and for a time president of the university; Joseph A. Holmes, professor of natural history, later state geologist and then organizer and first director of the U. S. Bureau of Mines; H. V. Wilson, head of the department of zoology for 44 years and now actively engaged in teaching as Kenan professor of zoology; and Collier Cobb, lately head of the department of geology.

Although the university seems at all times to have occupied a high place in the esteem of the citizenship of North Carolina, it has been only since about 1920 that the state has found itself in a position to make substantial appropriations for its support. The presidencies of E. K. Graham, Harry Woodburn Chase and Frank Porter Graham have covered the period of greatest physical expansion in buildings and equipment, in scope of instruction, in faculty and in number of students. Perhaps most prominent among the university buildings of recent construction are the library, the laboratory of chemistry (Venable Hall, where the scientific sessions of the academy will be held), Hill Hall (the home of the music department), the law building, Graham Memorial (the student activity center) and a thoroughly modern gymnasium (the Charles T. Woollen Gymnasium), which contains one of the largest indoor college swimming pools. At the present time, a large building is in process of construction to house the two-year medical school and the division of public health. Construction is about to begin also upon a laboratory of zoology, a dining hall and a number of dormitories for men and women. The renovation of several older buildings has been authorized.

In the minds of alumni, faculty and

DR. WILLIAM DE BERNIERE MACNIDER
DEAN OF THE MEDICAL SCHOOL, UNIVERSITY OF NORTH CAROLINA, MEMBER OF THE ACADEMY.

students, the new buildings are no more prominent than the old, including, first of all, Old East, the cornerstone of which was laid in 1793, making it the oldest state university building in the country. The South Building, begun in 1798 but first occupied in 1814, after being financed in part by the proceeds from a state lottery, is now the Administration Building. Of the dissimilar twins that arrived in 1822, Old West was completely renovated a few years ago, and Gerrard Hall, the old chapel, awaits an early and assured rejuvenation. Smith Hall (1852), once the library, now the Playmakers Theatre, although not among the oldest, may command the visitor's attention not so much because it is one of "the first state-supported theaters," but rather for a certain peculiarity of its architecture. On its pseudo-Corinthian columns and in accord with a suggestion of Thomas Jefferson, the classical palm-leaf motif was replaced by a more fitting American design of maize—ears, shuck and leaf with pleasing effect.[2]

Other branches of the university, as recently consolidated, are the College of Agriculture and Engineering in Raleigh and the North Carolina College for Women in Greensboro.

The country village of Chapel Hill, boasting of no major industry other than the university and located somewhere near the boundary between the Piedmont and the Coastal Plain, commonly elicits comment from visitors for its fine trees, its simple and pleasing homes and gardens, its environment of forested slopes, the distant views of low hills and plain and a certain intellectual and social atmosphere which seems to be felt by even the most casual visitor.

Closely associated with the university

[2] Unfortunately this building was recently damaged by fire, but as expressed by a sympathetic faculty member, the "roastin' ears" remained uncooked and undamaged.

DR. HENRY VAN PETERS WILSON
KENAN PROFESSOR OF ZOOLOGY, UNIVERSITY OF NORTH CAROLINA, MEMBER OF THE ACADEMY.

is the Elisha Mitchell Scientific Society, named, like Mount Mitchell, in honor of Elisha Mitchell, professor of mathematics and natural philosophy from 1818 to 1825, professor of chemistry and mineralogy from 1825 to 1857 and state geologist for a time. The "Mitchell Society," founded in 1883 by a group of faculty members, has, from the beginning, published a "Journal," the fiftieth volume of which, appearing in 1934, marked the corresponding anniversary of the society. One of the features of entertainment will be a luncheon given by the Mitchell Society to the academy on the first day of the meeting, Monday, October 24.

Near at hand, only about nine miles away, is Duke University, and through numerous cooperative and friendly arrangements, graduate students and faculty of each institution may avail themselves of library facilities or actual instruction in the other. The academy will be entertained by Duke University for luncheon on Tuesday, October 25, and in the afternoon will be shown over the university and its environs.

Members of the academy at the University of North Carolina are H. V. Wilson, mentioned in an earlier paragraph, and Dr. Wm. de B. MacNider, formerly professor of pharmacology and now dean of the medical school.

R. E. Coker

Chairman, Division of Natural Sciences, University of North Carolina

THE NEW DIRECTOR OF THE CAVENDISH LABORATORY

Announcement has recently been made of the appointment of Professor William Lawrence Bragg, director of the National Physical Laboratory, as the successor of Professor J. J. Thomson in the headship of the Cavendish Laboratory at Cambridge.

Bragg's career has been striking from its inception. Born in Adelaide, South Australia, in 1890, he was educated at St. Peter's College and Adelaide University there, and went to Trinity College, Cambridge, as Allen scholar. Very shortly after taking his degree in 1912, he joined his father, Sir William Bragg, in the latter's x-ray studies in crystal structure, begun about that time as a consequence of the discoveries of von Laue. So rapidly and brilliantly did this work progress that within three years the Braggs were jointly recipients of the Nobel award in physics.

The war interrupted the Braggs's work in crystal structure, and the son undertook the organization and direction of the British sound-ranging service, universally acknowledged to-day to have been consistently in advance of that of any other army. With the conclusion of conflict, Bragg returned to Cambridge, and was appointed in 1919 to succeed Rutherford in the Langworthy chair of physics at the University of Manchester. Here he further developed his work in crystal structure and built up a very powerful working group in the field, which attacked crystal systems of ever-increasing complexity, culminating in the famous studies of the silicates. The Hughes Medal of the Royal Society was awarded Bragg in 1931 for this work.

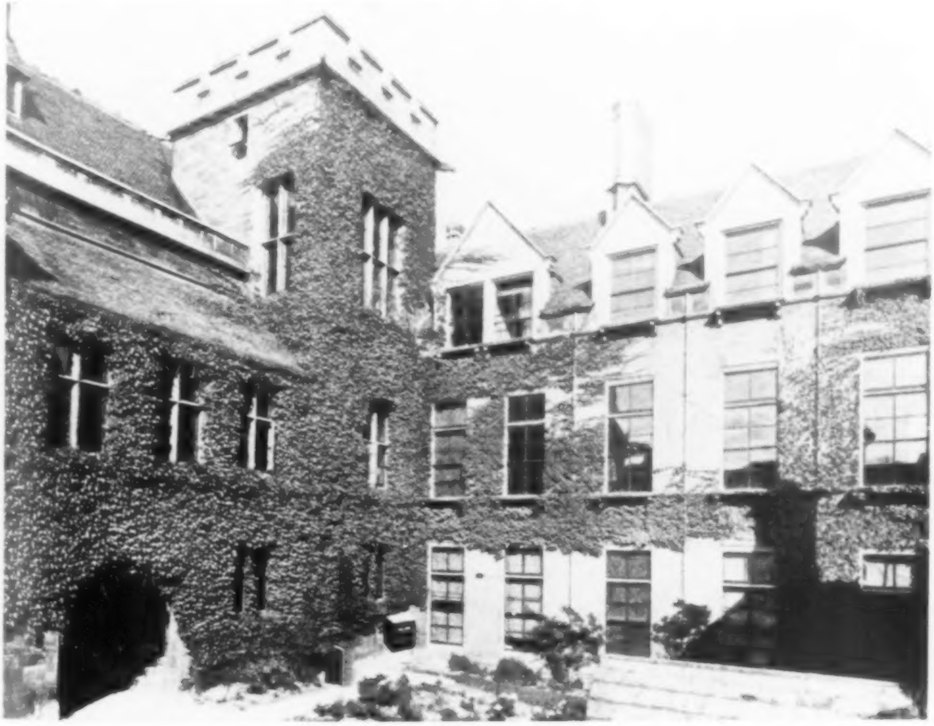
Recently Bragg has become much interested in the study of metal alloys of considerable complexity, especially three-component systems, from the standpoint of lattice structure, and from this important field, largely initiated and built up by Bragg and Bradley and their co-workers and students, stem most of our present ideas concerning super-lattices and the "order-disorder" theory. In 1937 Bragg was called to fill the post of director of the National Physical Laboratory at Teddington, and his new re-

PROFESSOR WILLIAM LAWRENCE BRAGG

sponsibility at the Cavendish comes to him after but a year in that office.

The Cavendish Laboratory has become so large that no one man can control it closely to-day. When one considers the long list of brilliant researches and brilliant workers that have been identified with the Cavendish since Maxwell accepted its directorship in 1874, it is hard to realize that two great physicists, Sir William Thompson and von Helmholtz, refused the post before it went to Maxwell, on the ground that there did not seem enough promise of development. Yet such seems to have been the case. Through the five years of Maxwell's directorship, however, and through the succeeding directorship of Lord Rayleigh, the Cavendish steadily increased in number of workers and in the volume and quality of the work which was produced. It was already famous when its directorship passed into the gifted hands of Sir J. J. Thomson, in 1884. And under the influence of this man, who of all leaders of the Cavendish has been linked the longest and most intimately with its history, it attained much of the preeminence which it enjoys to-day. That prestige continued to grow rapidly when Rutherford succeeded to Thomson's directorship in 1919, and steadily increased throughout his lifetime. The Cavendish has always been closely connected at once with theoretical studies and with those which directly affect practical affairs of living. Under its new leader it may be expected to be brought into even closer touch with the daily life of the world.

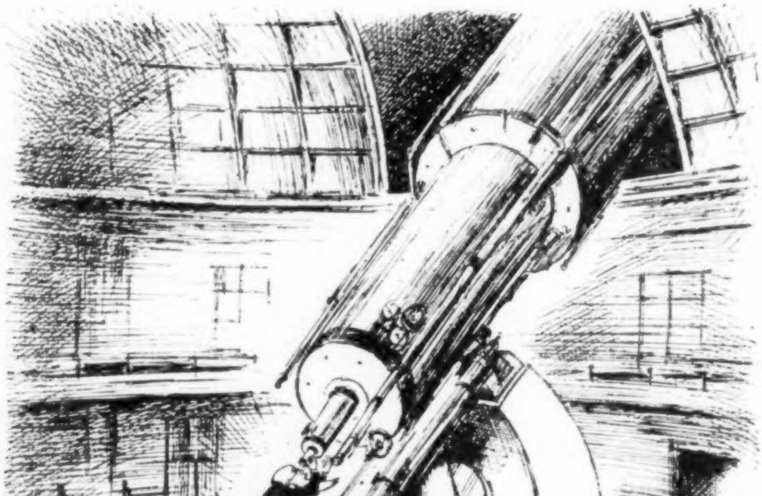
CARYL P. HASKINS
UNION COLLEGE



THE CAVENDISH LABORATORY

THE PHOTOGRAPH SHOWS THE ORIGINAL WING BUILT BY MAXWELL AND OPENED IN 1874.

THE ASTRONOMER'S WORLD



—From Punch.

"MY HUSBAND LIVES IN A LITTLE WORLD OF HIS OWN!"